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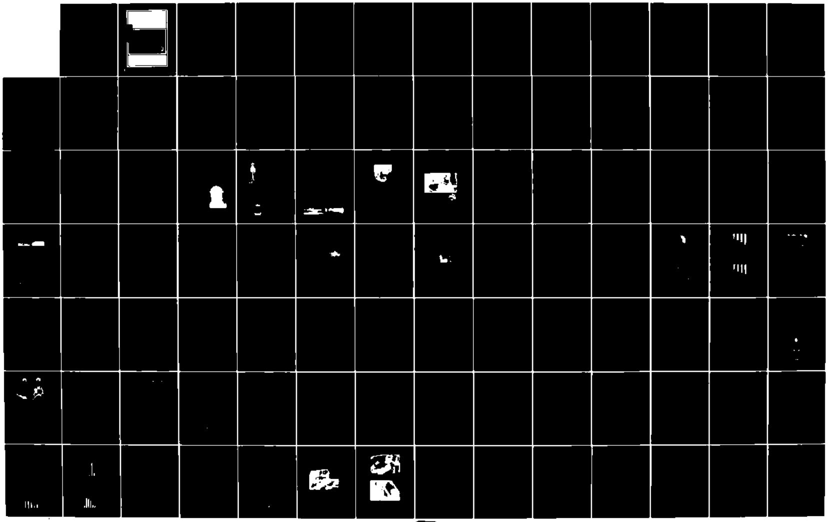

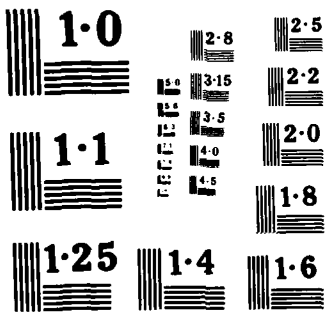
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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD LECTURE SERIES No.134

Aeromedical Support in Military Helicopter Operations

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Lecture Series No.134

AEROMEDICAL SUPPORT IN MILITARY HELICOPTER OPERATIONS

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PREFACE

This Lecture Series is intended as a comprehensive update for the flight medical officer and other personnel providing aeromedical support for military helicopter operations. The areas addressed include:

- stressful missions such as nap-of-the-earth flying, night operations, and operations under other unfavourable circumstances;
- extended operations, aircrew fatigue, and its monitoring and prevention;
- perceptual illusions, their generation and disorienting effects in helicopter flight;
- training and adaptation for countering disorientation;
- applied visual physiological requirements/standards for helicopter flight;
- visual protection and enhancement;
- acoustical hazards, auditory injury, hearing protection, and communications noise reduction;
- applied countermeasures for environmental extremes and the chemical warfare environment;
- helicopter accident and crash injury analysis, safety and crashworthiness design, and injury prevention;
- epidemiology, etiology, and prevention of back pain in helicopter pilots; and
- helicopter medical evacuation and rescue operations including evacuation of combat casualties.

This AGARD Lecture Series is sponsored by the Aerospace Medical Panel and implemented by the Consultant and Exchange Programme.

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AEROMEDICAL SUPPORT IN MILITARY HELICOPTER OPERATIONS

by

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This lecture series will be devoted to aeromedical problems and support in military helicopter operations. Dramatic increases in the number of helicopters in NATO military aviation and the increasing complexity of the helicopter aviator's mission, equipment, and environment demand a responsive and energetic effort by the aeromedical community.

Experience has shown that helicopter operations present work environments, special stresses, and environmental demands which are significantly different in type and degree from those in fixed-wing operations. Technological advances in communication, navigation, target acquisition, and weapons systems which have increased the effectiveness of helicopters have also increased aviator workload levels. These advances have brought about changes in helicopter air doctrine to include night and adverse weather operations and low-level flight, further increasing the demands on the aviator. Nap-of-the-earth (NOE) flight with night vision goggles (NVG) under adverse weather conditions demands the utmost levels of skill, training, mental acuity, and physical health. The burden of chemical, toxic, and laser protective equipment adds significantly to the combined stresses. The military helicopter aviator often lives in the vicinity of the ground soldier he is supporting and is subject to the same conditions and diseases. The pilot's ability to assimilate and integrate information, control the aircraft and its subsystems, and endure an uncomfortable and unfriendly environment is often stretched to an absolute limit. The flight surgeon must be able to recognize deteriorating mental and physical conditions. His role is critical because it demands he select pilots who will perform well, maintain both their health and high performance, as well as reduce the health hazards of the hostile environment.

Each facet of military helicopter aviation has its own unique set of man-related problems which must be supported effectively by aeromedical personnel if man, machine, and mission capabilities are to be preserved. This lecture series will deal primarily with those topics. Each lecture, hopefully, will contribute to a comprehensive review and update to facilitate active operational aeromedical support.

The topics listed below are those which were requested by the nations hosting this lecture series. It is anticipated that there will be some overlap of subject information among topics. This would be preferred to deleting important material.

A. - Stressful Mission Profiles.

1) - This should include a description of NOE flying, night operations, and operations under unfavorable circumstances to include adverse weather, unusual terrain, overwater and pinnacle operations. 2) Extended operations should be covered, to include mission duration guidelines, crew work/rest cycles, and monitoring aircrew for fatigue. The importance of effective command consultation also should be discussed.

B. - Visual Problems in Helicopter Operations.

This topic requires a review of visual physiology, requirements and standards, and visual protective and enhancement devices. Current electro-optics equipment such as NVG's, the integrated helmet and display sighting system (IHADSS), other visual display systems, laser protection, and cockpit lighting should be included.

C. - Disorientation in Helicopter Flight.

Those perceptual illusions occuring during flight should be reviewed, with emphasis on those most likely to occur in helicopter flight. Attention should also be given to those characteristics of helicopter flight which aggravate this already troublesome problem of aviation--hovering flight in all directions (to include poor adaptability of currently used instruments), inherent instability of the helicopter platform, and low-level flight with reduced visibility to include those conditions leading abruptly to decreased visual cues, such as dust and white-out.

D. - Noise and Hearing.

This section should include a review of hearing standards, noise hazards (including weapons impulse noise), hearing loss associated with helicopter flight, and state-of-the-art in hearing protective devices and noise reduction in communications. A current review of mechanisms of hearing loss would be appropriate.

E. Environmental Control.

This topic covers operational flight medical support for terrestrial elevations, temperature extremes, and the chemical warfare (CW) environment. In-flight countermeasures such as protective clothing and equipment, thermal cooling and heating devices, and fluid intake and output should be discussed.

F. Medical Aspects of Helicopter Safety and Crashworthiness.

This should be a review of causative and contributing factors in helicopter accidents (including midair collisions and wire strikes), crash injury analysis, and design for accident and injury prevention to include restraint systems, energy-absorbing seats, and personal equipment. Helicopter escape, ditching techniques, and postcrash fire hazards also should be covered. Vibration biodynamics in helicopter flight and the role of vibration in fatigue and low back pain should be included.

G. Aeromedical Support of Helicopter Medical Evacuation and Rescue Operations.

This topic should cover mission profiles in evacuation and rescue operations, in-flight resuscitation and medical support, in-flight monitoring, and evacuation of combat casualties including current doctrine for handling CW patients.

H. Preventive Medicine for the Deployed Helicopter Unit.

This lecture should review the application of general preventive medicine principles in monitoring and influencing control of food and insect borne disease, skin disease, heat and cold injury, self-imposed toxins, sanitation, nutrition, and physical conditioning. Discussion of predeployment preparation would be appropriate.

STRESSFUL MISSION PROFILES PT I

S. J. DURNFORD
Specialist in Aviation Medicine to the British Army on the Rhine

"Like all novices we began with the helicopter .... but saw that it had no future. The helicopter does, with great labout only what the balloon does without labour and is no more fitter than the balloon for rapid horizontal flight. The helicopter is much easier to design than the aeroplane but is worthless when done." Wilbur Wright. 15th Jan 1909.

SUMMARY

This is the first of two presentations that together are intended to examine the stressors inherent in the different types of helicopter mission that are currently in the repertoire of the NATO armies; together with their efforts on each other and on that most important stressor likely in any future European conflict - fatigue.

The emphasis is more on the practical than the theoretical aspects as the author is not so much a research scientist as a practising flight surgeon. Furthermore the exchequers of the World are mundane enough to demand some usefulness from their employees - and Aviation Medicine has much to offer in the fields of flight safety and efficiency.

This first portion of the presentation describes and analyses the stressors in those types of flight that might be considered particularly stressful - NOE flying, Night flying with and without aids, mountain flying, flight over water, flight in NBC clothing, instructional flying in peacetime and flight in adverse weather conditions. The stressors invoked by these flight profiles are set against the stressors found in all helicopter flying. Film clips will be used for illustrative purposes.

INTRODUCTION

The science of stress is not much more advanced now than was the science of aeronautics when Wilbur Wright composed the words in the above quotation 75 yrs ago. Wilbur did not get it completely right - which is perhaps lucky for those of us engaged in helicopter aviation medicine; but if pioneers such as we can make mistakes then so can we all. Some of what I say may well turn out to be less than true - the sad reality is that we know for too little about stress. The great leap in technological knowledge of the past few decades has allowed us to measure and predict how most parts of an aircraft will react to their environment and their duties but there is still one component - the aircrew - whose reaction to 'wear and tear' is still amazingly unpredictable. Ironically it is this component that is now most likely to fail in the presence of the increased physical, physiological and psychological loading imposed by that self-same leap in technology. This lack of data on the effects of human stress is not for want of research effort - the problem has been recognised for several years - but part of the difficulty lies in the fact that whilst individual stressors and their effects can be analysed in the laboratory the 'global' effect of all of them is dependant on so many variables that no useful predictions can at present be made. Data from the field is difficult to collect - and it is of course this data that is most important. The intuitive feeling is that the more the number of stressors the greater the likely impairment but this feeling has not necessarily been borne out by research. The next few years should show a great increase in knowledge in this field.

DEFINITIONS

Stress is a word that is well understood but poorly defined. In the past it has been taken to mean many things from "input load at work" (1) to "anything which stimulates the sympathetic nervous system" (2). This latter definition purposely includes such actions as getting up from a chair as even this simple event doubles blood nor-adrenaline levels. Producing yet another series of definitions may add to the semantic confusion but if - for the purposes of this lecture - the following words can be defined in the following ways it may prove helpful:

"stressor":- any alteration in a man's internal or external environment that may intuitively be considered likely to change his performance.

"stress" :- the global effect of one or more stressors.

"total stress":- the sum total effect of all the stressors acting at any one time.

These definitions are based on the performance aspects of stress partly because there is at present too little data correlating practical effects with biochemical or physiological effects. Because our techniques for assessing performance decrement are not as yet sensitive enough to measure all the effects of stress I have - rather lamely - ensured all stressors are included by allowing those which could 'intuitively' be considered detrimental.

It should be remembered that in performance terms stressors may counteract each other - for example it is well documented that the deterioration of performance due to fatigue at certain tasks such as responding to signals may be partially offset by the addition of another stressor - noise. (3) This does not mean that a tired man in a noisy environment is not under stress - it merely means that his performance in such a situation may be surprisingly good. I hope later to examine the possible explanations for this - and also for why performance in general may be maintained in the face of severe stress until 'unpredicted catastrophic failure' occurs. (O'Donnell 4)

It is usual to classify stressors into physical, physiological and psychological groupings. Table 1 lists 22 stressors that may be considered most important in military helicoptering under those headings. Although some - such as heat and cold - are mutually incompatible, most may be simultaneously combined. When one considers that each stressor may exist over a wide range of severity the final number of possible permutations is virtually endless.

How this final permutation is produced depends - in general terms - on four factors:

- Background stressors from day to day living.
- The characteristics of the aircraft and weapon systems flown.
- The environment within which the flight takes place.
- The mission requirements (including the type of flying required).

TABLE 1.

22 COMMON STRESSORS IN MILITARY HELICOPTERING.

PHYSICAL	PHYSIOLOGICAL	PSYCHOLOGICAL
Noise	Hypoxia	Increased workload
Vibration	Hypoglycaemia	Boredom
Heat/cold	Drugs - poisons	Anxiety
Comfort	Disorientation	Fear
Pressure effects	Cirradian rhythm abuse	Anger
Acceleration	Muscle fatigue	Frustration
Radiation (sunlight and others)	Dehydration	FATIGUE
		Sensory deprivation
		Sensory overload

BACKGROUND STRESSORS

It is too often forgotten that the stressful undercurrents of everyday life provide a significant foundation upon which the stressors of flying are superimposed. It is a generally held - but by no means proven - belief that the stress of modern life is increasing. The author considers that this belief stems from the frustrations that grow as bureaucracies blossom and spawn complicated, detailed rules affecting all aspects of day to day existence. Certainly it must be true that the physical and physiological stressors encountered in modern western living (in areas such as housing, heating and health) are <u>less</u> now than previously experienced. Whether or not the psychological stressors have actually increased is not known - and is perhaps irrelevant - as it is <u>perceived</u> psychological stressors that humans react to. The fact that a senior squadron commander recently told me that he believes that it is stress encountered on the ground that is now the greatest flight safety hazard in military helicoptering quite likely makes it so - for him at any rate.

Table 2 lists those stressors commonly found in the general environment. For this table I have departed from the usual convention and have tabulated the stressors under the headings 'domestic', 'work related (non flying)', 'work related (flying)', and I have split the table into 'peacetime' and 'wartime' sections. It should be noted that not only may an aviator carry anxieties into the air with him but he may also carry heat load, noise fatigue, hunger, illness and other physical and physiological stressors.

One particular point is worth making - this is that the flight safety hazard may not centre on aircrew being distracted by domestic or work worries whilst flying, it may on the contrary result from aircrew 'leaving their earthbound cares behind them' and attempting to seek relaxation in the clouds.

It should also be observed that the immediacy of war may actually reduce the number (but not severity) of background stressors. Perhaps we should pay more attention to the stressors found in peacetime - maybe improved performance in wartime is partly a function of a <u>reduced</u> total stress!

TABLE 2.

SOME BACKGROUND STRESSORS ENCOUNTERED BEFORE FLIGHT

DOMESTIC	WORK RELATED(NON FLYING)	WORK RELATED (FLYING)	
Marital problems/Sex	Squadron Ground duties	Flight planning	PEACETIME
Money problems	- training/sport	- notams	
Family/social stressors	- 'paperwork'	- met.	
Health/Alcohol/Nicotine	- lecturing (!)	- liaison with tasking authority	
Insurance	General Soldiering	- aircraft serviceability	
Legal matters	- heat load from NBC kit	- authorisation	
Overnutrition	- training	- briefing crew(s)	
Separation from family	- promotion exams	Incident reports	
Irksome minutiae (tax forms, parking tickets etc)	- admin duties	Missed meals	
	- range firing	Irksome minutiae (servicing of helmets and flying clothing, aircrew medicals etc)	
	- 'gas'chamber		
	- 'fitness' tests/runs		
	Irksome minutiae (official lunches, guard duties etc)		

DOMESTIC	WORK RELATED (NON FLYING)	WORK RELATED (FLYING)	
Family - where are they? Are they alright?	Soldiering: - maintaining the base and its defences - enemy action - ? NBC - drugs - sleep deprivation - sleep distortion	Flight planning - IFF codes - plans/mission - safe corridors - friendly & enemy forces - met. - briefing crew(s) Frequency of sorties (+?nite fli?) HLS moves	W A R T I M E

The title of this presentation is stressful mission profiles and I do not intend to delve any deeper into the background stressors from day to day living - but it is a foolish flight surgeon who does not acknowledge their existence.

CHARACTERISTICS OF AIRCRAFT AND WEAPONS SYSTEMS

However, before approaching the actual mission profiles it is worth considering how the idiosyncracies of the different aircraft may affect stress. That they do so - at least in the fixed wing world - has been shown by Hale (5). Helicopters vary considerably in their production of physical stressors - not merely from one type to another but sometimes also between different aircraft of the same type. Below are listed three common stressors and some of their effects.

Noise. The cabin noise level of the Chinook (110 dBA) is approximately 15% higher than that of the Gazelle (95 dBA). These figures are approximate as noise levels depend on the flying manoeuvre being performed. How much of this noise reaches the aircrew and how stressful it proves to be depends on a variety of factors such as the frequency of the noise and attenuation by helmets. The noise environment of a helicopter is to be addressed in a later lecture and will therefore not be analysed in detail here. It has been well shown however that a high intensity of noise (95 dB) tends to reduce performance but that total silence is equally unfavourable. (3,6) 'Mild' levels of noise may improve performance at tasks such as rate of work and false detections and may assist in reducing the effects of fatigue. Whether the noise is impulsive or continuous does not seem to matter - although it has been reported that the significance of the sound signal does (speech being most important for example, then noise, then music). This improvement in performance is against intuitive expectations - and is also against aircrew subjective experience. The actual effects on performances of noise on aircrew at work requires further evaluation in the field.

Two further aspects to noise effects should be considered - firstly, whether or not noise improves individual performance it can certainly make communication difficult and secondly, the stressor effect of noise is not confined to the aircrew in the aircraft (who actually may be protected against the worst of it) but may most affect aircrew on the ground and groundcrew.

Vibration. Rotary wing aircraft vibrations span a wide range of frequencies up to 300Hz (7). The effects depend largely on the frequency as well as the amplitude and include hyperventilation (8), improvement in performance (3), fatigue (muscular and mental)(7) and even diarrhoea (7).

As with noise, the subject of vibration is too large to receive justice in a brief paragraph intended merely to set the scene in which missions are flown. However, it is subjectively reported by aircrew that coping with vibration utilises valuable 'spare capacity' whilst they are flying and leaves them at the end of a sortie feeling more exhausted than necessary. This may in part be due to the physical difficulties of focussing on instrument panels and keeping control movements steady. Vibrations at 3Hz with an amplitude of 2.7 cm may reduce visual acuity by 30%. (18)

Vibrations commonly have their sources in the rotor head but it must not be forgotton that weapon firing, air turbulence and changes in flight path may be significant factors. If resonance is allowed to set up the results may be extreme - for example 'ground resonance' between rotor head and skids in contact with the ground may literally destroy an aircraft in a matter of seconds.

Comfort. The problem of 'helicopter backache' is also to be addressed in a later lecture. To what degree discomfort is a stressor is difficult to say - but yet again it is intuitively assumed to be a distraction and a waste of 'spare capacity'.

THE ENVIRONMENT WITHIN WHICH THE FLIGHT TAKES PLACE

There is one other source of stressors against which the stressors inherent in the actual mission profile must be set - and this is, of course, the environment. The review here of environmental stressors will again be brief on the grounds that they are the subject of a later presentation.

Heat Stress. It may be that heat load is the single stressor that has been most experimentally explored in the past. It is one that cannot be ignored in the context of NBC operations (9, 10). The effects of thermal stress on short term memory, detection of visual signals, complex tasks and simple tasks have been noted (11, 12, 13, 3) and guidelines given for tolerance limits (14).

In general terms it has been suggested that slight heat stress increases flying performance over control levels but that this improvement is eliminated by more severe heat stress (15). It is possible that performance under severe heat stress breaks down in part because of reduced in-depth consideration of problems.

It should be noted that subjective sensation of heat stress may not tally with objective findings and that "cognitive and aviation performance do not provide sufficient lead time before the onset of physiological systemic heat load to be very effective as alerting mechanisms." (15)

Cold Stress. Cold has also been shown to affect performance (6) and helicopter operations in cold areas have been the subject of attention (16). However in the case of cold I have been unable to find any references suggesting improved performance. Because it is generally easier to protect aircrew against the cold than it is to protect them against heat, cold is of less practical significance - but bulky clothing may be physically limiting and may lead to heat stress when worn during bursts of activity.

NBC operations. Apart from the heat loading it should be remembered that wearing NBC clothing has psychological effects (17). Indeed merely knowing that one is operating in an NBC environment may provoke anxiety.

There are other physical stressors inherent in NBC operations - mostly minor but perhaps of importance when considered globally. Aircrew initially find it irritative and distracting to have to overcome the increased resistance to head movements. Visual fields may be reduced in some assemblies. Multiple minor stressors may have accentuated effects (6).

Nighttime, Adverse Weather and Terrain Type might also all be considered environmental conditions - but they all affect flying technique sufficiently for them to be considered below under "Mission Requirements. (including type of flying required)".

MISSION REQUIREMENTS

General. The above - somewhat sketchy - preamble was required if one is to understand how the stressors resulting from the type of mission flown are embedded in the total stress.

With regard to mission requirements it is perhaps worth noting that the roles of the helicopter have not greatly altered through the years. A close relation of the helicopter - the autogyro - was tested by Lt Gregory in the 1920's for its ability to carry out armed action and reconnaissance. Like Wilbur Wright he contrasted it to a balloon but this time the decision went in the autogyro's favour. The machine was not however considered as useful as a fixed wing aircraft.

Armed action and reconnaissance are still the prime roles of the military helicopter but demands on performance arising out of the Korean, Vietnamese and other conflicts have combined with technology to revolutionise the efficiency with which the helicopter can perform its functions.

The present day roles of the helicopter are:

- Armed action
- Reconnaissance
- Direction of Artillery Fire
- Assistance with Command and Control
- The Movement of Men and Material (including Casevac)

The emphasis on the importance of the individual roles varies from nation to nation - for example the U.S. places more importance on helicopter casevac than the U.K. does.

All the roles may be carried out in a variety of geographical and climatic conditions - although some conditions may encourage a particular use of the aircraft (for example casevac from mountainous terrain). Identical climatic and flight path conditions infer similar physical and physiological stressors whatever the helicopter's role - but slight differences may occur, for example with the noise and vibration of weapon firing. Psychological stressors such as workload and emotional content may, however, be widely different. For example the pilot of a scout aircraft engaged in an anti tank mission may find himself talking to several different people on different radio nets whilst navigating, flying Nap of the Earth (NOE) AND chosing suitable fire positions. His is the highest workload I know of in any job (for short periods at least). The aircrew involved in a casevac mission on the other hand may feel frustration, anxiety and guilt as a casualty they are carrying deteriorates and dies. Reports from the Falklands conflict suggest that aircrew were poorly prepared to handle the psychological stress of ad hoc casevac.

We do not know enough to accurately analyse how these differing psychological stressors will affect performance. My personal belief (based on intuition rather than science) is that reserves of energy, mental strength and self discipline will maintain performance levels (whatever the nature of the stressor) until the reserves catastrophically fail.

Stressors Specific to the Individual Roles

ARMED ACTION. This at present infers anti tank missions but may well involve anti helicopter missions in the future. The techniques of these missions involve high workloads (see above) and perhaps a high sortie rate. Missile firing and proximity to the enemy will bring their own stressors. Flying is, of course, NOE.

RECONNAISSANCE AND DIRECTION OF ARTILLERY FIRE. The techniques for these roles are not much different to those for Armed Action (above) although the aircraft is at present unarmed. Again there is a high workload, a high sortie rate and unpleasant proximity to the enemy. Flight is generally NOE.

ASSISTANCE WITH COMMAND AND CONTROL. This involves flying at distances somewhat further behind the FEBA - but that does not imply a huge increase in safety. Returning enemy aircraft and our own anti aircraft weapons may present bazards. Flight will be NOE.

MOVEMENT OF MEN AND MATERIAL. Casevac is scheduled to be dealt with later in the series. Helicopters provide a useful means for the speedy transfer of shock troops - the Soviets know this and have many heliborne soldiers. Flying techniques may be complicated by large all up weights or flight with underslung loads. In the latter instance vibration pattern may present a problem and NOE flight becomes more difficult.

Required Flying Techniques For Different Situations. At this point I would like to show a video clip taken from a British anti tank training film. It shows many of the stressors already mentioned and demonstrates NOE flight - the stressors of which I intend to tackle in a moment.

V I D E O C L I P

In case you didn't find the film stressful I show this slide of the airgunner who starred in the film. No tests were done on him but he subjectively felt stressed after less than an hour's flying time on an ordinary German Summer's afternoon.

NOE Flight. The importance of avoiding enemy radar was recently demonstrated when the French lost a Jaguar in Chad to fire from a ZSU 23-4 (an equipment of the Soviet tank battalion and a potent anti helicopter weapon). Flight at below radar levels (hopefully) is stressful in many ways:

- Psychologically, it presents a high workload and proximity to the ground and hard centred obstacles may provoke anxiety.
- It requires constant changes of heading and height and may thus be a disorientating experience (particularly when large angles of bank are used). This effect is of course worse at night.
- Vibration may increase as a result of air turbulence close to the ground as well as from the frequent changes of rotor disc configuration.
- Muscular workload is high because of the constantly required control inputs which have to be extremely accurate at such low level.

Possibly the greatest stressor of NOE flight is the high sensory, muscular and cognitive workload. Attempts to measure the workload using techniques such as eye movement analysis, inspired gas volumes and physiological parameters have confirmed this workload (19, 20, 21, 22, 23). As yet, however, there is very little data available from which one can draw a base line for the purposes of quantifying 'workload'. This is obviously a high priority of research.

The fatiguing effect (both somatic and psychological) may be compounded by psychological factors such as anxiety secondary to the physical hazards. Ability to concentrate may diminish and anxiety progressively increase. There is some evidence from laboratory studies that men under stress may maintain their overall performance levels by bursts of extra mental effort. This approach is not productive with NOE flight because the nearness of hazards require sustained performance. In other words stress research done on discrete tasks such as command post tasks in a laboratory may only be read over to the stress of NOE flight with great caution.

The other prime stressor associated with NOE flight arises from the continual accelerations in all three orthogonal axes as the aircraft weaves its way around obstacles and up and down valleys. The subsequent sensory input is very high and may be disorientating. Because NOE flight is so 'visual' any vestibular inputs are, I suspect, continually overridden with ease - but the results may be fatiguing. Impaired visibility increases the disorientation risk.

Changes in vibration patterns may have specific effects such as making it difficult to read maps.

Somewhat perversely I would at this stage like to point out that not all military missions are set in the scenario of a European War. In Northern Ireland, for example, military helicopters customarily fly at 2000' or more to avoid small arms fire. Observation helicopters in Northern Ireland may spend 2 hours hovering at 2000' - and the continual demand on flying skills required to maintain the hover may combine with the 'boredom' of the task to produce a unique stress of its own that aircrew subjectively find very fatiguing.

<u>Night Flying</u>. There are two distinct types of flight by night:

- simple unaided night flying
- flying with night vision aids (NVGs)

SIMPLE NIGHT FLYING. NOE flight by night is generally impossible without aided vision. Radars don't, however, sleep; thus until recently military helicopter night missions have been confined to moving Helicopter Landing Sites (HLSs) and other 'rearward' flights. Nonetheless, simple night flying is enough of a technique of its own to deserve mention.

Compared to daytime flight, the 'straight and level' flight of night contains fewer sensory, motor and psychological stressors. There is little heat, turbulence and drama. Navigation may involve a higher 'maths over map' element than equivalent navigation by day, and this may be stressful to some.

There is another element - however - that of anxiety secondary to the poor visibility. To a certain extent this was exemplified in a recent confession in a flight safety magazine. The author, a recently qualified pilot, followed the other aircraft of his flight on a night move. The first pilot down read off the QFE of the landing site to the other pilots but unfortunately made an error that put the HLS a fewer hundred feet lower than it was. The rest of the flight made routine approaches and afterwards commented that the lighted landing aid has seemed to disappear halfway down the downwind leg. On discovering the error the following morning they were all aghast to find that a small hillock would have blocked their view of the aid while they were downwind. The author of the article flew the circuit in daylight and was more than a little frightened to find that the whole flight must have flown UNDER a set of wires on the downwind leg! There are several elements to this story including the dangers of flight at a circadian 'low' for performances after a hard day's flying. It also demonstrates that it is what you <u>perceive</u> that gives you stress - on the night of the incident they were all as blithe as sandboys.

NVG FLIGHT. Flying with image intensifying aids is a very different technique. Past generations of NVGs provide good examples of 'aids' that in fact make the aviator's life more difficult by enticing him to fly to his physical and psychological limits. Future aids - whilst being 'easier' to fly with are likely to increase the aviator's workload by removing his traditional night's rest.

Essentially NVG flight involves an attempt to fly using daytime (NOE) techniques using the enhanced vision from the goggles. All the stressors peculiar to NVG flight are superimposed on those of NOE flight and thus the total stress can be considerable. By its nature night flying occurs at times of circadian 'lows' and this may compound the problem.

The problems unique to NVG flight are:

- Reduced visual cues, secondary to a 90% reduction in field of view (a central field of 40° compared to the usual 130°) and monochrome vision distorted and interrupted by 'noise'. Amongst the visual cues that become particularly important is 'ground texture'.
- An increased likelihood of disorientation secondary to an increased frequency of head movement accompanied by reduced visual references.
- An increased reliance on instruments (for cross checking visual references) but <u>NO</u> true IF scan pattern. The frequent looking 'in' and 'out' of the cockpit carries obvious disorientation and obstacle contact hazards.
- Difficulties in reading instruments and maps in the low light levels of the cockpit.
- The possibility of odd and on occasions disconcerting illusions secondary to 'eye on a stalk' effect and field magnification. The likelihood of illusions is much reduced with the newer, shorter, more appropriately designed goggles.
- Physical hazards on impact.
- Temporary visual changes and 'after images' following return to normal vision.

There is no doubt in my mind that unless aviators using these devices receive strong medical back up including appropriate education and sensible duty rostering accidents are inevitable. The German Army has shown that safe NVG flight can be achieved.

<u>Instructional Flying</u>. Although this is not a wartime role it takes a high priority in peace.

Olaf Skjenna states that he considers helicopter instructing to be the most stressful occupation in flying (24). The instructor can never relax because the student is unpredictable and the margin for error is very small. The sortie rate may be higher.

Dr Skjenna found that the alcohol intake of rotary wing instructors was 50% higher than that for fixed wing instructors. 92% of helicopter instructors considered that their job was more hazardous than flying jet fighter aircraft.

A quick count of the last 10 U.K. Army accidents shows instructors to have been involved in 6 (although only 2 accidents occurred with non qualified students). The statistical significance of this is unclear but it might be concluded that instructors deserve as close if not closer stress monitoring than other pilots.

Mountain Flying. This is similar to NOE flying in that it requires frequent changes of control inputs and flight close to hard centred objects. There are however important differences:

- Flying techniques are different and demanding primarily because wind direction and speed are so variable in the hills. Readers who are pilots may remember hovering in AUTOROTATION above a crest and trying to land on it by inching forward and down.

- Psychologically the mountains may be disconcerting. Pilots used to constant ground hogging may dislike being close to a crest one moment and high above a valley the next. There is a well known tendency for pilots doing a circuit out over a valley before coming back into a bowl or crest to unconsciously descend over the valley.

  Perception problems are exacerbated by the bleak mountain sides with few landmarks or objects of known size to assist in estimating distance and height. There is a danger that scrub trees may be perceived to be fully sized with the result that the pilot greatly overestimates his distance or height above them. Slopes are disconcerting to aircrew accustomed to roughly horizontal horizons.

- Psychological stressors may be made more problematical by hypoxia. From 4,500' equivalent altitude learning new tasks becomes less easy. Night vision is impaired - as is day vision from 12,000' (without oxygen). At 8,000' reaction time to complex choice reaction tests doubles (and what is mountain flying if it is not a complex choice task?). Mental time sharing and mental filtering ability are notably reduced. Fatigue may be exacerbated and self critiscism is lost (8, 24).

- Glucose metabolism may be impaired from 5,000' (24).

- The physical stressors of altitude - cold and pressure effects - may be marked. Aircrew may be tempted to dress in a manner comfortable for their lowland base.

  The classical pressure problems associated with the closed and semi closed body cavities need no explanation from me.

Flight over Water. One might consider that flight over water would be easy in comparison to NOE flight, mountain flying or most other land flying. Indeed the workload of a simple over water transit flight is not high. There are no obstacles requiring avoidance and most flight is straight and level - (or perhaps hovering if a mission is being performed).

A number of accidents, however, attest to the fact that it is not so easy as it would appear. The classical cause is height misjudgement due to a featureless (often calm) sea. Indistinct horizons may also be a problem. It requires only a short lapse in concentration to allow the aircraft to descend into the water - and at 120 kts or more the result may be catastrophic. Lapses in concentration may be induced by the 'boring' nature of the flight.

There are some stressors associated with flight over water that are worth mentioning:

- Protective clothing sufficient to provide survival in the water may be uncomfortable in the cockpit. Dinghy packs may be attached to the man in such a way as to cause restriction of movement and alteration of normal posture.

- Specific flying techniques are required for ship board landings. The landing area in these cases is usually small and a 'confined area' bordered by aerials and metal bulkheads. The landing surface itself may be pitching and rolling. Gusting winds may provide particularly difficult landing conditions.

- Psychological factors. Although underwater escape and other survival techniques may be well taught aircrew may have a horror of ditching. There may be a constant low level of anxiety whilst flying over water (particularly if the aircrew are not used to it).

  Other aircrew may experience 'break off' phenemenon after a period of time of straight and level flight over a featureless sea.

Adverse Weather Operations. These are a very potent source of psychological stressors. Helicopter aircrew are accustomed to low level flight with constant and vigilant visual contact with the ground. Although they are usually trained for instrument flying and keep 'current' they usually look upon an instrument recovery to an airfield as a last resort. Many would rather put down in a field and wait for the weather to clear. This is partly due to the fact that many NATO helicopters carry few if any navigational aids. There is another factor however - if the cloud base is that low then there may be few airfields in the area open, and the cloud may contain hard centred obstacles such as mountains (the so called cumulo-granite).

The psychological stressors of low level flight in poor conditions are fairly self evident - reduced visibility breeds anxiety, strong winds may make navigation troublesome, and the constant decision making as to whether to push on may be fatiguing. This latter factor may be complicated by factors such as 'press on-itis' where social commitments or other drives exist to encourage the pilot to fly beyond the limits. The risk of icing from freezing rain or inadvertent cloud entry may be a worry. Making a landing may in any case be difficult because the terrain may well not be suitable. Perhaps the most stressful situation might be flying over unsuitable terrain in poor visibility with low cloud at below $0^{\circ}C$ in an aircraft with no de-icing facility.

There are physical and physiological factors as well. Continual turbulence may induce muscular and mental fatigue. Disorientation secondary to poor visibility and constant turbulence is a risk. Cold stress may be present. Poor visibility may be compounded by dusk or night time light levels.

There are some particular skills required in adverse weather conditions. For example it may be necessary to use a O/o technique landing on snow (or sand).

CONCLUSION

The concept behind this part of the presentation has been to give an overview of the large variety, variability and unpredictability of the stressors found in helicopter missions. There is however one particular stressor possible on all missions which I have not mentioned because I intend to cover it in the second portion of the presentation - this stressor is 'fatigue' due to abuse of circadian rhythms,long duty hours and poor quality rest. In the second half I also hope to cover the effects of stress generally.

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STRESSFUL MISSION PROFILES PT II - WORKLOAD AND FATIGUE

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"It is the final straw that breaks the camel's back." English Proverb.

SUMMARY

This part of the presentation deals with how the stressors described in Part I combine with factors within the man (such as previous training) and the demands of the actual flying mission to produce an overall 'workload'. The manner in which different levels of workload may affect performance are discussed and methods that might be used by Flight Surgeons to reduce aircrew workload levels are covered. The impact of future technology is briefly considered.

As with Part I, the emphasis is more on the practical than theoretical aspects.

WORKLOAD

In Part I an analysis of stressors was approached from the classical viewpoint of physical, physiological and psychological groupings - but research now seems to be moving to a position where stress is considered simply as part of a global picture involving not only ambient stressors but the task demands AND the operator's capacity to fulfil them. The sum total of these has been used as a definition of workload, in other words:-

"Workload is viewed as an hypothetical construct that conveniently summarises the multiple interactions which limit operator task performance." (1) This is obviously a much more practical approach - and provided it can be successfully implemented it should prove of great benefit in the definition of acceptable and unacceptable workload levels. The problem is that - as we have seen in Part I - it is not always easy to forecast the effects on performance of a combination of two simple stressors, let alone a mixture of all the stressors, all the human factors and all the task demands.

In order to demonstrate the difficulty I have expanded by original table of the stressors found in military helicoptering to include task demands and human capacity factors (Table I - Workload Factors.)

TABLE ONE

SOME WORKLOAD FACTORS

STRESSORS		HUMAN CAPACITY FACTORS	TASK DEMANDS
Physical:	Noise	Intelligence	Vigilance levels
	Vibration	Natural aptitudes	Number of 'problems'
	Heat/cold	Personality	Urgency of 'problems'
	Comfort	Training	Complexity of individual problems
	Pressure effects	Motivation	Novelty of individual problems
	Accelerations	Mood	Variety of individual problems (mathematical/spatial reasoning etc)
	Radiation (including sunlight)	Comprehension of the situation and the task aims	Strength of sensory input (and level of 'noise')
		Performance feedback	
Physiological:		Arousal level	Reaction Effort required
		Sex	Time on task
	Hypoxia	Age	Memory loading levels
	Hypoglycaemia		Solution monitoring requirements
	Drugs/poisons		
	Disorientation		
	Circadian Rhythm Abuse		
	Sleep loss/distortion		
	Muscle fatigue		
	Dehydration		
Psychological:			
	Boredom		
	Anxiety		
	Fear		
	Anger		
	Frustration		
	Fatigue		
	Sensory deprivation		
	Sensory overload		

Because it is at present obviously impossible to produce workable theoretical models to predict how the factors interact, most current research appears aimed at inferring workload levels from measured human responses. (The responses used include EEG changes (2), biochemical results (3), inspiratory volume changes (4), beat to beat heart rate, sinus arrythmia and other physiological variables (5).)

There is a hazard in this - in that 'workload', by definition, partly consists of a number of highly personal variables within the subject's own make-up. Identical external conditions can still lead to very variable responses and thus difficulty in applying the results generally. This is not necessarily a drawback, however, as human subjects in the field are as variable as those in the laboratory and it is conclusions that can be applied to field operations that are required.

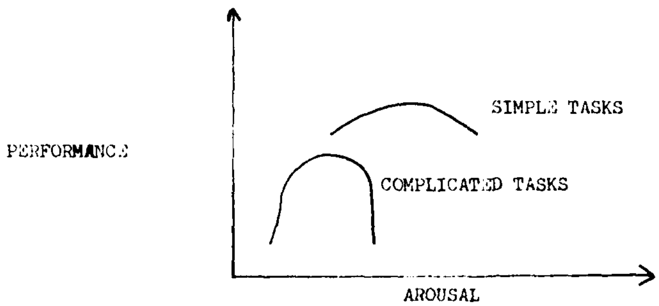
WORKLOAD AND PERFORMANCES

It is established that "the effects of workload may be extremely subtle in their early stages, since the human shows an incredible ability to maintain performance for long periods of time under severe stress. The problem is that human capacity is ultimately limited." And it is also established that "in the vast majority of cases performance of the human being on a motivated primary task does not degrade gracefully - rather performance is maintained at a high level until catastrophic failure." (Both quotes from O'Donnell, (1).)

How humans may maintain their performance levels at 'near normal' levels in the face of great difficulties is not well understood and is naturally the subject of much research.

Theoretical background. It is 76 year since Yerkes and Dodson first produced their famous model of how performance was influenced by 'arousal'. The familiar inverted U curves for 'simple' and 'complicated' tasks are given below (figure I). No doubt the reader already knows them well.

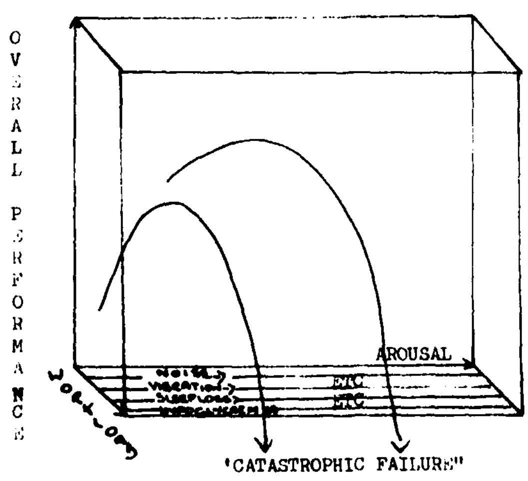
Figure I



The essential principle is that 'cortical arousal' is a state of wakefulness that can vary from deep sleep to blind panic - and that somewhere in between there is an optimum level for performance. Arousal is a function of the reticular system and may be assessed by use of the EEG. As stressors act on the man so the level of arousal is altered and performance is varied accordingly. For example noise is said to increase arousal and sleep deprivation reduce it. Personality is said to have an effect - extroverts are supposed to require external stimulus to achieve the same level of arousal that introverts naturally have.

This is a very simple and easy model for explaining how stressors may combine to keep performance reasonably steady - and one can add a third dimension - 'workload' - to illustrate eventual operator failure.

Figure 2. Operator Failure



(This diagram is purely for conceptual purposes and is not meant to have any great scientific meaning. It is possible, for example, that eventual failure occurs through the arousal systems - in which case the diagram would of course be invalid.)

The arousal/performance curves, however, have come under critiscism for being TOO simple (6, 7, 8, 9). This is partly because in neurophysiological terms it is difficult to understand why an increase in cortical activity should lead to impaired performance. As a possible answer Defayolle pointed out that the human has a 'processing capacity' of about 15 bits - but that the sensory information reaching the brain may be as great as 10^7 bits. If I understand it correctly, he took the concept of a 'filter' originally suggested by Broadbent and proposed a model whereby increased arousal caused reallocation of capacity away from 'filtering' duties towards 'processing' duties. Thus less of the input to be 'central processor' had been filtered and consequently a higher proportion of what was actually 'processed' was irrelevant to the task in hand.

It must also be stated that modern concepts are beginning to use the basis of a number of 'pools of resources' (1) for different elements of the cognitive process rather than one simple and single reserve.

Whatever the realities, the Yerkes Dodson Curves certainly present useful models for understanding performance under stress - but perhaps they should be viewed with caution in some areas.

There is one other element I would like to mention - and this is motivation. It is an intuitive feeling which has been backed up by research (10) that motivation is important in maintaining performance.

I would suspect that motivation is really hust another word for conscious expenditure of effort in controlling arousal levels - i.e. that motivation keeps arousal at an optimum even when stressors might be trying to push it one way or ther other. (That conscious effort does affect arousal can be shown by transcendental meditators - and, possible, by those of you in the audience who are still awake!) When eventually the man accepts 'defeat' his motivation goes, his arousal level immediately shifts and 'catastrophic failure' occurs. Perhaps the concept of the 'prescriptive zone' could be borrowed from thermal physiology - (where it is used to describe the extents of the termal environment in which 'normality'of body temperature can be maintained by appropriate physiological responses) - and applied to describe the extent to which motivation can compensate for workload.

INDIVIDUAL FACTORS

Table I lists 46 factors that may affect workload and thus performance. To analyse each individually is not possible in this short time and in any case some have been assessed in Part I of the presentation. There are some factors, however, that are of especial practical significance in that Flight Surgeons may be able to vary their impact on aircrew.

STRESSORS

Circadian Rhythms and Sleep Disturbances

AGARDographs no. 247 and 270 both contain extremely useful advice on circadian rhythms and organising work/rest schedules. Their full titles are, respectively, "Significance of Circadian Rhythms in Aerospace Operations" by Klein K and Wegmann H (11), and "Sleep and Wakefulness Handbook for Flight Medical Officers" by Nicholson A and Stone B (12).

CIRCADIAN RHYTHMS. It is generally true that performance peaks at between 1200 - 2100 hrs and reaches a low at between 0300 - 0600. This is so for the following tasks:

1. Flying a F104 simulator.
2. Cancelling symbols.
3. Adding 2 digit numbers.
4. The psychometer 'Kugel' test.
5. Latency and detection in vigilance.
6. Card sorting tasks.
7. Choice reaction tasks.

The rhythm for performance at these tasks closely follows the rhythm for body temperature but it is likely that there is no causal relationship between the two (13). Performance varies by about -15% to +10% of the mesor (rhythm adjusted mean).

The one task variable that differs is memory loading. For tasks involving immediate memory the performance rhythm peaks in the morning, has a 'low' at between 1400 and 1500, and then rises again in the evening. This performance curve closely resembles that of the stress related hormones.

The importance of circadian rhythms lies in the organising of shift work. Because fatigue reduces arousal any change due to circadian influences in the presence of fatigue is likely to occur on the steepest part of the Yerkes-Dodson curve and thus have an exaggerated effect on performance. (Figure 3)

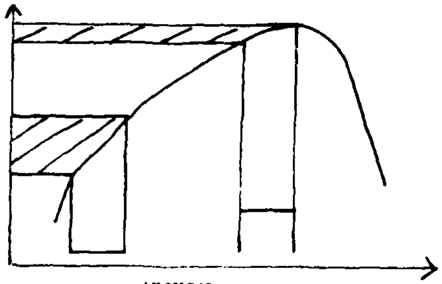


Figure 3. The effect of identical changes of arousal on performance when initial arousal is low or near optimal (After Klein).

Thus one may say that in organising night work one should avoid operational fatigue coinciding with the circadian low. This has been borne out experiemtnally (6). Therefore for complex tasks such as night flying (particularly with NVGs) one should avoid long duty periods extending into the early hours of the morning. One should instead begin the duty period shortly before the 'low' if only one 'low' is going to be experienced during the duty period. If the duty is to extend more than 24 hours it becomes imperative to avoid the duty ending at or just after a 'low'.

Unless a long period of shift work is planned (> 10 days) one should try to avoid two or more consecutive nights shift work as rhythms may begin to shift.

The amplitude of circadian rhythm of performance can be reduced by staying awake through one night - but then becomes increasingly larger as sleep deprivation continues. Motivation can also reduce the circadian variation (11).

In summary:

- time duty periods to end before a nocturnal 'low'
- avoid consecutive night shifts unless a long 'adapted' period is planned
- if duties are mentally or physically strenuous make nocturnal duty periods shorter - e.g. 6 hrs
- more elderly persons (over 50 yrs of age) and very young (under 18-20) may not be able to accept shift work as well as those in between.

SLEEP DISTURBANCES. It is generally acknowledged that it is very difficult to prove performance decrement as a result of sleep deprivation - at least over short periods OR periods where some sleep is allowed (11, 12, 13). Subjective "Fatigue" is usually complained of before performance can be shown to be reduced and thus 'physiological cost' rather than 'performance decrement' has been viewed as the more meaningful term (13).

In particular it has been difficult to show any relationship between the type of sleep deprivation (REM, stage 2, 3 or 4) and performance. On the other hand the time at which sleep is taken and the time of the performance have been shown to be significant (13).

Thus 36 - 48 hrs of total sleep loss has not caused consistent or uniform reduction in performance - although motivation and knowledge of how long the experiment is going to last may be factors in this (6, 14). On the other hand it is stated that - from the point of view of the type of work envisaged - "Long, work-paced, complex tasks with high attention and vigilance requirements and no feedback on performance can be expected to show high sensitivity to total sleep loss." (13)

With regard to partial sleep loss - no marked deterioration in performance has been shown in subjects allowed 3 hrs sleep a night over 8 days, 5.5 hrs/night over 60 days or 5 hrs/night over 3 months - although subjective fatigue was marked.

It has been suggested that time of sleep and interval time between sleep together with the time of performance is more important than length of sleep in 24 hrs. In one study it was found that a group of subjects who 'napped' at 0400 - 0600 after 45 hrs sleep deprivation and who napped again at 1200 - 1400 (53 hrs of sleep deprivation) suffered detrimental effects on performance after the first nap compared with a control group who napped only after 53 hrs. The 53 hr nap was beneficial in both groups. Possible explanations include the effect of circadian rhythm (15). In another study on a U.S. carrier off Vietnam, pilots were found to have a much greater variation in sleep to sleep interval than the ships crew. The greater the variation of the sleep to sleep interval the greater the number of landing errors.

Furthermore, and of great importance to air operations, it has been suggested that the "social effects of prolonged wake and irregular work may be more important than the effects on psychomoter performance". (16) In other words interpersonal relationships may break down - and this might be of importance in command and crew structures.

In the South Atlantic campaign, the long haul crews who might have been expected to suffer sleep disturbances were offered Temazepam to assist them in obtaining sleep. Performance remained good and morale high (17). In a European War there would inevitably be many distractions limiting the ability of off duty aircrew to sleep. Short acting hypnotics might be of use here - although the operational problem lies with unforeseen and sudden demands on aircrew who have just taken the drugs.

Apart from hypnotics the use of psychostimulants has been advocated. After all, faced with the reality that night work as well as day work will be required in any European conflict, it would be nice to be able to turn aircrew 'on' and 'off'. At present the stimulants under investigation have proved to have problems - but the outlook for the future looks better. There is no doubt that some drugs such as caffeine and amphetamine can abolish the effects of fatigue (12, 18), but the long term cost of using stimulants is not yet established.

In general terms, although objective measures of performance have not necessarily confirmed subjective assessments of fatigue, flying is such an unforgiving task - particularly in the military environment described in Part I - that efforts must be made to minimise 'workload' by minimising sleep disturbance. Furthermore, as it is suggested that fatigue may be cumulative, adequate rest periods must be given after duty periods involving sleep disturbance.

Thus it seems reasonable to try to ensure that aircrew get as much sleep as feasible (8 hrs +) - and that at least some of this sleep occurs regularly at the same portion of the 24 hr cycle - preferably at night. Any total sleep loss should be followed by a lengthy (at least 24 hr) rest period to regain efficiency.

Time on Task

Lorry drivers driving at night have less than the mean number of accidents in the first 4 - 5 hrs of driving but more than the mean number of accidents after this point. Also, high speed train drivers have an increase in signal defective errors after 90 mins driving. Neither of these two activities can be directly related to the complex task of military flying - but it might be supposed that military flying is more sensitive to 'operational fatigue'. (See 'fatigue' below.)

It has been suggested that time on task is less important than time of sleep and time of performance (6) but this effect may not be true in periods of prolonged operations.

Part I of the presentation should have demonstrated that different mission profiles have different 'stress' profiles - and different workloads. To make a blanket statement about time on task limitations would therefore be meaningless. Some tasks must be interspersed with frequent rest periods - others need not. Commonsense combined with science and subjective reports from the aircrew must indicate the limits.

Physical Factors

Noise, comfort, vibration, head load and other physical stressors can all have an effect on performance - and certainly affect 'workload'. Since physical variables are amongst the easiest modified by the aviation medicine fraternity they must not be overlooked.

Emotional Stressors

Paratroops experiencing pre-jump anxiety initially demonstrate increased ability to detect visual patterns. As the anxiety increases, however, their correct interpretations become fewer although the number of failures in actually noticing the signal also become fewer (8).

As with all psychological stressors, it is difficult to quantify anxiety. This doesn't really matter as a Flight Surgeon's main interest is in preventing emotional stressors from providing a flight safety hazard and the same principle that the research workers use for measuring workload - namely that the man can be used as his own instrument for measuring stress - is available, If a man says he is a flight safety hazard then he should be treated as such. However, as will be seen from Part I and what I have said so far in Part II, objectively measured performance usually fails long after subjective feelings of impaired performance have appeared - in other words humans tend to 'fail safe'. There are exceptions to the rule - notably in conditions where self critiscism also fails (as in hypoxia). Most of these don't affect helicopter operations. The one important one that does is fatigue.

Fatigue

Fatigue - whether it be defined as the 'result of excessive workload' or 'the reduced efficiency of the central nervous system secondary to prolonged usage' (both definitions appear in the literature) - is seldom seen in peacetime operations BECAUSE we very sensibly prevent it. Senior officers in the next World War (if there is one) will nonetheless require advice on fatigue limits to obtain maximum efficiency from their troops. This is particularly true of the outnumbered force (NATO).

If one accepts the formulation that 'stress is a part of workload and workload leads to fatigue' (13) as the basic definition then we can say that fatigue will depend on a balance of 'fatigue increasing' stimuli such as noise and anxiety and 'fatigue reducing' factors such as adequate rest and proper training. Performance may well remain high in the presence of fatigue because of the 'extra investment of effort'. Cumulative fatigue may however overcome this motivation and sudden collapse will then occur. On the other hand there is some evidence that performance is not always maintained - in the early days of NOE flying the U.S. Army was training its pilots with a schedule involving 8 hrs flying/day. Subjective fatigue was reported and 3 blade/tail rotor strikes were reported. (This phase involved 60% of the total training programme.) The flying hours were then reduced to 4 hrs a day and the subjective fatigue reports stopped. There was only one incident in the remaining 40% of the total programme. There are obviously far too many variables for it to be possible to conclude that the reduced 'fatigue' caused the reduced incident rate - but its a possibility.

The problem - as always - is one of quantification. Because performance has remained stubbornly intact to the last moment it has proved a poor measurement of fatigue. Physiological measurements of 'cost' have proved better indicators and subjective assessments have proved most sensitive of all. However - "in militaristic terms if there is no decrement of performance then it is axiomatic that the workload must be acceptable." (1) Alas, there is eventually a decrement in performance and when it occurs it is unpredictable and costly in human (and military) resources. Individual variability, task demands and performance feedback all seem to have a large effect on when this failure occurs - but at present we are unable to unravel the interactions of the factors. However fatigue is NOT inevitable if we adjust work/rest schedules and task demands approximately. Because we do not know exactly where this appropriate balance lies (and it is in any event dependant on other factors such as heat/noise levels in aircraft etc) we should strive to prevent commanders driving their troops to the limits of efficiency - and this limit may be marked by an epidemic of sudden failure.

There is one other factor I feel should be mentioned and this is a repeat of a comment I made in Part I. It is possible that performance is retained in overall terms by intermittent bursts of extra mental effort. However, military flying (NOE flying in particular) is very much a vigilance task which requires sustained effort. Failure at this task may thus occur earlier than one might otherwise predict.

It has been suggested that during periods where fatigue is likely (exercises and war) - a flight surgeon should be on hand to:

- monitor aircrew for fatigue
- provide briefings
- ensure that aircrew are not loaded with extra duties
- ensure adequate accommodation/feeding
- ground fatigued aircrew - as a joint decision with the subject and the ops officer

It has also been suggested that Flight Surgeons should monitor aircrew on a routine basis by administering fatigue check lists - although it was pointed out that this might cause extra paper work for already overworked aircrew (23).

HUMAN CAPACITY FACTORS

Personality

'Aviation character' is something that has concerned civilian as well as military administrators (19).

Apart from the 'risk taking' propensities of extroverts/introverts, neurots/stable subjects (stable introverts are least likely to take unnecessary risks) there is the question of how different personalities develop different strategies for dealing with 'stress'.

In one study pilots under emotional stress were evaluated on a DC 4 link trainer after their psychotherapy sessions. One group of 'anancastic' pilots were compared against a set of controls. The 'anancastic' group had greater maintenance of flying skills but were less likely to notice appropriate warning signals. In other words they were disturbed by their ruminant worries. The control group, on the other hand, showed impairment of flying skills but quick recognition of warning signals - their errors were errors of commission; the anancastic group's errors were those of omission (20).

In another study the ability of air traffic controllers to cope in sustained operations was studied and it was suggested that 'defensive' personalities showed poor performance at the task when under stress (21).

Flight surgeons may not change the personality of their patients but they may recognise the type (and thus the risk) and they may advise on selection.

Training

Repeated practice at a complicated task eventually leads to that task becoming a 'simple' one. There can be no higher priority for a flight surgeon concerned with planning for war than to emphasise the requirement to shed wartime workload NOW by comparatively overtraining in peacetime.

Motivation

There are several reports in the literature (6, 10) that motivation and proper briefing can improve performance - and even in one instance restore performance to normal levels after sleep loss (6). Urinary stress indices reflect the uncertainty a man feels if he doesn't know how long he will have to go without sleep (14).

Flight Surgeons can encourage efficiency by advising on definite pre planning of duty rosters and adequate briefing of duties - together with feedback of performance.

TASK DEMANDS AND FUTURE DEVELOPMENT

By giving advice on designing mission rates and profiles the Aviation Medicine fraternity may prevent aircrew from being underloaded or overloaded. Whilst 'operational requirements' may often be quoted as overriding medical requirements it should be pointed out that efficiency and flight safety is the common goal of both operations staff and medical staff. Flight Surgeons have a unique knowledge to give to the military planners - and they should not allow themselves to be overridden without good cause. In point of fact most military planners are only too happy to accept medical advice.

For the future, as technology removes more of the 'manual' labour from aircrew and increases their spare capacity for 'higher level' cognitive performance so fatigue and other stressors inherent in the workload may become more important. Furthermore technology will allow operations in increasingly adverse weather conditions (or at night) thus adding to the burden of aircrew. It is interesting that just as appreciation of pilot workload has led to the '2 crew' concept becoming an actuality in European helicopters, so the U.S. Army is planning a new helicopter for early next century (the LHZ series) as a single seater.

In physiological terms, tilt rotor and advancing blade concepts may give 'helicopters' many of the characteristics of speed and performance that are now displayed only by fixed wing aircraft - whilst allowing them to retain the ability to hover and move slowly. As this happens so the physical and physiological stressor envelope will enlarge with factors such as 'G' becoming important.

I do not wish to open myself to the possibility of making a mistake like Wilbur Wright's, but I think that not only are helicopters here to stay - they are likely to take over some fixed wing roles. If they do so then proper medical designs of the workload elements will be essential.

CONCLUSION

In practical terms Flight Surgeons may ease the aircrew burden by:

- Monitoring physical stressors such as heat load/vibration.. They may give advice on the effects of these stressors and how to combat them.

- Monitoring physiological stressors such as alcohol intake (which may be a sign of stress but which will also increase stress). Giving advice on nutrition, accommodation and other matters of 'comfort'.

- Monitoring psychological factors both at home and at work - and protecting aircrew from excessive pressure. They may assist in aircrew selection.

- Advising on training requirements for safe operation under conditions of high workload. Advising on fatigue and giving guidelines on 'time on task' and other limitations.

- Assisting in the design of operational situations and mission profiles so that:

    - duty rosters are sensibly employed

    - unnecessary workload is avoided

    - 'choke' points of workload are avoided where possible

    - combinations of unfavourable stressors (such as hypoglycaemia and hypothermia) do not occur

- Above all, by ensuring that aircrew are well informed of their own physical and psychological limitations. As Dr Skjenna said "A pilot is his training spends a considerable amount of time learning about the vagaries of meteorology and the intricacies of his machine, but precious little is devoted to studying the most vulnerable part of the system - himself". (24)

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VISUAL PROBLEMS IN HELICOPTER OPERATIONS

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SUMMARY

Helicopter operations pose many visual problems for aircrew. These range from factors degrading vision both externally and internally within the cockpit, to the protection of aircrew against ocular hazards.

This paper discusses the importance of ocular physiology, visual standards, transparency optics and cockpit lighting systems in ensuring an adequate level of performance. Ocular hazards from impact, nuclear flash, chemical warfare agents and lasers are discussed and related to the advantages and disadvantages of protective equipment. The paper concludes with a review of some of the devices currently available for visual enhancement and the problems associated with their use.

INTRODUCTION

Military helicopter operations impose severe demands on vision. Helicopters fly close to the ground at night, frequently under adverse weather conditions. A camouflaged, hidden enemy must be discovered and then destroyed. The crew may be compelled to protect themselves against nuclear flash, lasers, chemical warfare agents and impact. This protection must be integrated into aircrew equipment assemblies together with devices for visual enhancement.

VISUAL PHYSIOLOGY

It is convenient to divide ocular function into its three component parts, namely the detection of light, form and colour.

The eye is capable of functioning over a wide range of illumination levels. The threshold stimulus for the eye is below 10^{-5} lux, and the maximum limit, where discomfort is evident, above 10^{5} lux (bright sunlight at altitude). Two mechanisms function over this range. Scotopic or rod vision operates from threshold to approximately 10^{-2} lux and over this range the ability to see detail is poor and vision is monochromatic. Above 1.0 lux, photopic or cone vision is the dominant mechanism giving, with increasing illumination, the twin advantages of good resolution of detail and colour vision. The transitional stage, between 10^{-2} lux and 1.0 lux, when both rods and cones are functioning, is known as mesopic vision and ranges roughly between a quarter and full moonlight (Fig 1).

The retina requires time to adjust to varying luminances because the mechanism is photochemical. When the retina adapts from dark to light the adjustment is rapid, but in adapting from light to dark the adjustment is slow and biphasic. As can be seen from the dark adaption curve (Fig 2), there is not a steady increase in sensitivity. The curve is in two portions, the initial adaptation being that of the cones and the slower adaptation, that of the rods. In helicopter flight at night, due to the necessity of reading instruments, recognising terrain features or using night vision goggles (NVGs), vision is either lower photopic or mesopic. A further feature of rod and cone vision is their different colour sensitivity. Rods are most sensitive to blue/green light and cones to yellow/green light (Fig 3). This differing colour sensitivity, which is known as the Purkinjé phenomenon, is evident at dusk when a red colour appears to be dark, whilst a blue colour, subjectively, retains its brightness.

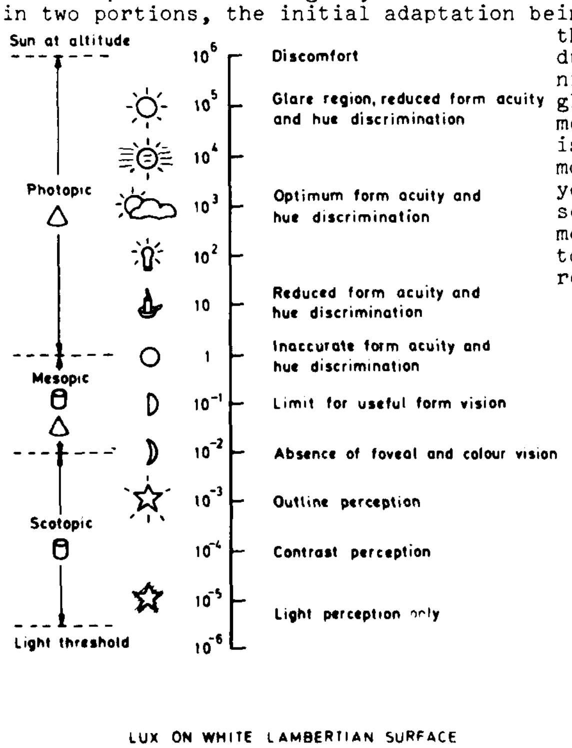

Figure 1. The variation in ocular function and performance with increasing illumination.

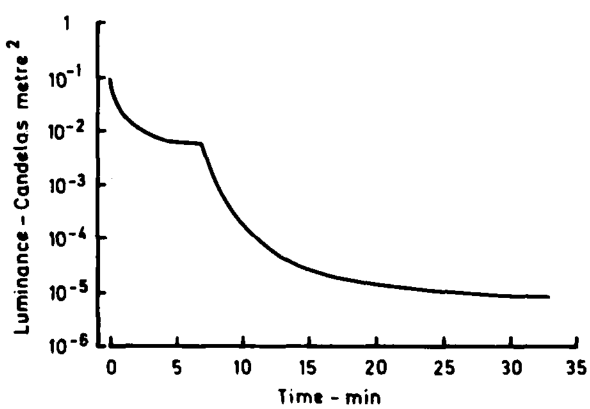

Figure 2. The dark adaptation curve of the eye.

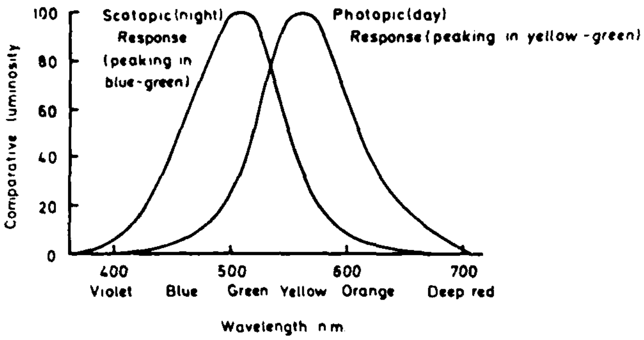

Figure 3. The photopic (cone) and scotopic (rod) spectral sensitivities of the eye

When one looks at an object it is imaged on the fovea and the surrounding macula. The fovea is a specialised region of the retina composed entirely of cones. It is where vision is clearest and colours are most readily seen. Peripheral to the fovea the retina is composed of both rods and cones, the ratio of rods to cones increasing and visual acuity decreasing, with distance from the fovea.

A consequence of this double mechanism for light appreciation was the adoption of red lighting systems to maintain night vision. It used to be customary to wear red goggles in lighted crew rooms and to use red cockpit lighting since rods, unlike cones, are insensitive to the longer red wavelengths. The advantage of preserving rod adaptation is, usually, unnecessary as few helicopter roles can be performed with rod vision. In most operations the visual acuity provided by the cones is imperative. The disadvantages involved with red cockpit lighting systems in interpreting coloured maps and legends, the absence of colour fringes, which are a sub-conscious aid to rapid focussing and the extra focussing effort required to read in red light, far outweigh any theoretical advantage in maintaining rod adaptation. Some current cockpit lighting systems designed for compatibility with NVGs are a blue-green colour, which destroys rod adaptation.

Under good conditions the eye can resolve detail which subtends a visual angle of 30 seconds of arc. However, under some special circumstances much finer resolution is possible. A single line may be differentiated against a plain background when it subtends a visual angle as small as 0.5 seconds of arc. This is more a measure of contrast than of resolution, but it is important in helicopter operations, as cables or wires may first be sensed by their contrast against the sky.

Factors which may influence the resolution of the eye are:- atmospheric conditions, the optical quality and cleanliness of interposed transparencies, ocular pathology or the requirement for spectacles. The large pupillary diameters which occur at night may render more evident the visual decrement caused by refractive errors (Fig 4) by reducing the depth of field of the eye.

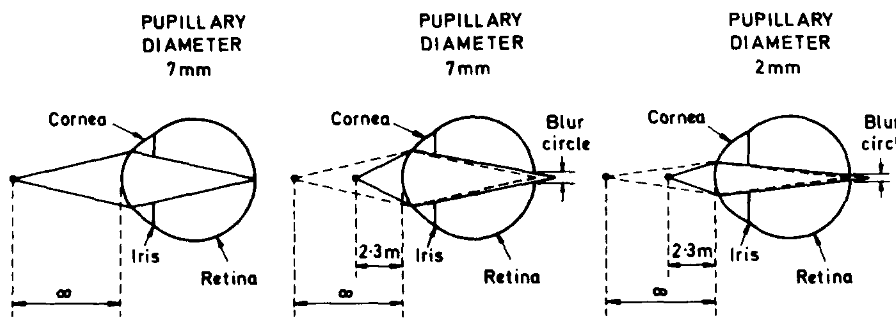

Figure 4. Diagram showing decrease in blur circle size produced by a reduction in pupillary diameter. An eye focussed at infinity with a pupillary diameter of 2mm has a depth of field extending to 2.3 metres.

Recognition of objects is also profoundly influenced by the inductive state of the retina. One part of the retina modifies the function of another part. This is known as spatial induction. In aviation, spatial induction will enhance the recognition of targets against the sky. The bright sky diminishes total retinal sensitivity and a grey target, therefore, appears darker, with a consequent increase in the contrast between it and the sky. If the adapting stimulus is coloured the reduction in sensitivity will be hue dependent and complementary colours will be seen more readily. However, a stimulus on a portion of retina will also affect function of that portion to a subsequent stimulus. This is known as temporal induction or light adaptation. If a bright object forms an image on a portion of the retina, the sensitivity of that retinal area will be depressed for a considerable period of time. This may cause low contrast targets, imaged on that area, to remain unseen.

Visual acuity is also influenced by contrast between target and background and by the luminance of the target. Sharpness improves with increasing luminance, up to a moderate level, beyond which no further increase occurs and at very high luminances, may be impaired. The best resolution is achieved when the luminance of the target and the ambient lighting are similar; a significant disparity will reduce visual acuity.

Colour vision is a function of cones and therefore of photopic vision. According to the generally accepted theory of colour vision, there are three classes of cones present at the macula, in the ratio of 1:10:10. These cones have absorption peaks for blue (440 nm), green (540 nm) and red (580 nm). The combination of the yellow macular pigment filter and the absence of blue cones at the fovea causes central blue blindness for small objects or lights subtending visual angles of less than one degree. A combination of the three primary colours, in the correct proportions, is seen as white light, and by varying the proportions and saturation (addition or subtraction of white light) any other colour can be matched.

A feature of colour vision is the processing of the signal from the eye. The brain "sees" that which it expects to see. If an individual wears coloured spectacles he very rapidly adjusts to the colour change and he then "sees" objects in the colours he would expect and mistakes can occur. A similar phenomenon occurs with form vision when the eye is presented with limited information. The brain may fill in the remainder of the scene it is expecting to see, resulting in gross errors of interpretation.

VISUAL FUNCTION IN FLIGHT

There are a number of visual problems which are peculiar to aviation and the following are particularly relevant to helicopter flight.

Empty field myopia occurs when the eye is deprived of visual cues at infinity. In ocular terms this is any distance in excess of 6 metres. Under these conditions the eye frequently focusses to between 1 and 2 metres making the aviator temporarily short-sighted. Should another aircraft enter his field of view it may not be seen due to blurring of the retinal image. The conditions likely to cause this problem are flight at night, in cloud or whilst flying over featureless terrain such as sea. Aircrew should periodically look at features at infinity in order to relax their accommodation. The conditions causing empty field myopia may also cause feelings of detachment and isolation - the "Break Off" phenomenon.

Vibration may cause great difficulty in reading flight instruments, maps or charts. The vibration is in the range 1-50 Hz (typically 12-18 Hz) in the Gz axis. It is most evident whilst flying at high speed or during the transition to hover and the hover itself, Harding (Ref 1).

Autokinesis in rotary wing aircraft may occur whilst looking at lights, such as stars or aircraft navigation lights, against blank backgrounds. After a short interval the lights appear to wander randomly. These apparent movements occur if the background does not provide sufficient information about the normal involuntary eye movements. These movements are then interpreted as movements of the lights. This phenomenon may occur during the hover at night, when single lights are seen against a featureless terrain, particularly when the lights are on moving vehicles. Autokinesis was one reason for the abandonment of ultra-violet instrument lighting. The glowing phosphors on pointers and numerals, particularly when background illumination was inadequate, provided the conditions required for the illusion.

Flicker, produced by the chopping of sunlight by trees, helicopter rotors or by anti-collision lights and strobes can cause epileptiform episodes. The problem arises when the frequency is between 5 and 20 Hz being maximal at about 12 Hz. Modern strobe lights, normally, have a flash frequency below 2 Hz and should be harmless.

Depth perception is of great importance in helicopter flight. The binocular cue of stereopsis can provide distance judgement at ranges of up to 1 kilometre. The monocular cues of parallax, ground texture, perspective, relative size, overlapping contours and, to a lesser degree, aerial perspective, are also of great value. In the hover and during landing many of these cues, particularly ground texture may be degraded by dust, rain or snow, and the upward motion of these contaminants through the rotors may be misinterpreted as helicopter ascent.

VISUAL STANDARDS AND CORRECTIVE EYEWEAR

Visual acuity is the ability of the eye to discriminate detail and is a measure of foveal function. It may be expressed as the reciprocal, measured in minutes of arc, of the angle subtended at the eye by the detail resolved. The normal method of recording visual acuity in the U.K. is the metre system: 6/6 means that the eye is able to resolve at 6 metres, detail which the "normal" eye should be able to resolve at that distance. 6/60, for example, means that the eye is only able to resolve at 6 metres that which the "normal" eye can resolve at 60 metres. The converse applies to 6/4 when the eye resolves at 6 metres that which the "normal" eye can only resolve at 4 metres and vision is thus better than normal. The U.S. system is expressed in feet, (Fig 5) gives the approximate equivalences of the U.K., U.S. and decimal systems.

U.K.	U.S.	Decimal
6/3	20/10	2.0
6/4	20/13	1.5
6/4.6	20/15	1.3
6/5	20/16	1.25
6/6	20/20	1.0
6/9	20/30	0.7
6/12	20/40	0.5
6/15	20/50	0.4
6/18	20/60	0.3
6/21	20/70	0.28
6/24	20/80	0.25
6/30	20/100	0.2
6/36	20/120	0.16
6/60	20/200	0.1

Figure 5. Approximate visual acuity equivalences

Visual standards for aircrew entry vary widely from nation to nation, sometimes being dictated by the availability of recruits rather than by the requirements of the visual task. It is general, however, to insist that the corrected visual acuity be at least 6/6 for each eye and to demand a higher uncorrected visual acuity for pilots and for helicopter winchmen who may have difficulty using spectacles. As myopia may be progressive and can cause severe visual decrements at distance, the permissible error is usually lower than that for hypermetropia. The current entry standards for pilots in the U.K. are 6/12 6/12 correctable to 6/6 6/6. The refractive range allowable is -0.75 D to +2.50 D in any meridian. The astigmatic element, which is the unequal refraction of light in different meridians, must not exceed +1.25 D. For helicopter loadmasters the standard requires a visual acuity of 6/9 6/9 correctable to 6/6 6/6, the refractive range being -0.25 D to +3.00 D in any meridian; the astigmatic element not to exceed +1.25 D. A dioptre (D) is defined as the reciprocal of the focal length of the lens expressed in metres.

Standards also exist for near vision, ocular muscle balance, colour perception, acceptable pathology, visual fields, and in some nations for stereopsis, dark adaptation and glare resistance. For further information it is suggested that national standards be consulted.

In determining entry visual standards for helicopter aircrew it is prudent to consider the range of visual equipment currently available and that being developed for the future. When this is related to the complexity of helicopter operations, and the adverse conditions under which they may be flown, it may be considered that entry standards should be stringent to ensure that the man does not limit the machine.

Corrective spectacles for use in flight, should offer the maximum field of view, be lightweight, non-irritant, robust, comfortable and compatible with existing and projected aircrew equipment assemblies. The lenses should be fabricated from lightweight material of high optical quality, offering the maximum available impact resistance. It is suggested that coated polycarbonate and CR39 resin be the materials of choice. When abrasion is likely, thin chemically toughened glass may be more appropriate.

A problem encountered by aircrew particularly on search and rescue operations is encountered when flying with the aircraft side windows open. Spray on their lenses, especially sea spray, causes a considerable decrement to vision. Presbyopic aircrew who wear bifocals or half-eye "granny" glasses sometimes complain of great difficulty in vertical descent during an "engine off" landing. This is caused by looking downwards through the reading segment. Bifocals should be prescribed with the smallest flat top "D" segment compatible with an adequate near field of view of flight instruments. This should allow a satisfactory lower lateral field of view for descent. "Granny" glasses should either be doffed or lowered down the nose prior to descent. Winchmen may require distance spectacles to be secured by a cord, to prevent loss in gusty conditions over sea, when contamination by salt may preclude the use of visors.

Soft contact lenses have recently been trialled by seventeen officer aircrew, Brennan (Ref 2). They were subjected to the most adverse conditions likely to be encountered in military helicopter operations. The stresses included vibration, climatic extremes, "G" forces and the prolonged wearing of an aircrew respirator. The results indicate that from the environmental standpoint contact lenses would be suitable for helicopter aircrew. There are, however, problems concerning the wide scale adoption of contact lenses by aircrew primarily concerning maintenance under field conditions, tolerance, ocular pathology and the problem of foreign bodies either gaseous, liquid or solid. Any decision would need to balance their advantages with these disadvantages.

PERSONAL AND ROTOCRAFT TRANSPARENCIES

Visors

It is considered essential that aircrew be provided with protection against solar glare and impact. Bird strike due to the lower speed of helicopters is not a significant hazard, at present, but may become so with future higher speed aircraft.

Protection against solar glare is best provided by a hinged, tinted visor with an adequate luminous transmittance. The density of the tint is determined by the ambient luminance against which protection is required. The design aim is to allow the eyes to operate in the luminance region in which maximum acuity and contrast discrimination is achieved, approximately 10^3 cd/m^2, which corresponds to external luminances on cloudy days. In temperate regions a 15% luminous transmittance is a reasonable compromise. It is essential that the tint does not impair colour discrimination. It is suggested that a non-metameric neutral grey tint be adopted, with a substantially flat transmittance in the

visible band 400 nm to 780 nm. The visor should also give protection against ultraviolet in the UV(A) (315-400 nm) and UV(B) (280-315 nm) bands and, if possible, against near infra-red radiation in the IR(A) (780-1400 nm) band. 1400 nm is the upper-limit at which the eye transmits radiation to the retina. Visors should also provide protection against wind blast and impact, they must be lightweight, compatible with aircrew protective helmets and offer the maximum possible field of view. The material of choice is injection moulded polycarbonate treated with an anti-abrasion coating. Helicopter operations demand the utmost in optical quality particularly relating to depth judgement. It is of great importance, therefore, that the visors be as near afocal as possible. The prismatic deviation, particularly binocular algebraic summation at conjugate points, must be kept to the minimum, especially in the vertical and horizontal base in meridians. Clear visors intended for use at luminances less than 10^4 cd/m^2 should conform to all the foregoing parameters and their luminous transmittance should exceed 85%.

Rotocraft Transparencies

These transparencies vary widely in optical quality depending on construction,Kay (Ref 3). The helicopter transparency is the last in a long chain of transparencies or devices through which the aviator may look. These include corrective spectacles, visors, respirators, laser protective filters, nuclear flash protective devices, NVGs, displays, sights and de-icing systems. It is important, therefore, that the optical quality of a transparent enclosure is adequate for the role intended. The major factors to be considered are luminous transmittance, haze, distortions, resolution, secondary image separation and inclusion size and frequency. For panels used in conjunction with weapon aiming systems the absolute deviation is of importance, as is the binocular deviation of parallel rays, separated by the inter-pupillary distance, when using binocular optical aids.

In a survey carried out amongst helicopter crews most complaints were related to obstructions in the field of view, reflections at night and inadequate rain clearance or de-icing systems. These deficiencies in ancillary systems were regarded as being of greater importance than optical quality.

COCKPIT LIGHTING

As previously discussed the theoretical advantages of a red cockpit lighting system in preserving rod adaptation is outweighed by its disadvantages. It has been generally accepted that white light systems,dimmable to extinction are preferable,Agard (Ref 4).

The aim of cockpit lighting is to ensure that instrumentation can be accurately and quickly interpreted, whilst at the same time not degrading dark adaptation to an extent incompatible with recognising terrain features or other aircraft, at realistic night time luminances ($>10^{-2}$ cd/m^2). Lighting can be provided by emissive or reflective displays and it is important to ensure that a satisfactory balance is maintained across the cockpit. A low level of background lighting should be provided for visual reference, together with suitable anti-dazzle lighting. The limits of the chromaticity coordinates for both blue filtered white, white, and red light systems are given in Stanag 3224 - "Aircrew Station Lighting".

At night under low levels of illumination it will be impossible to fly Nap of the Earth (NOE) missions without visual aids. A device increasingly being used are NVGs. These are essentially photon multipliers and will be described later. In order to prevent the flooding of NVGs with light and to enable other cockpit personnel not wearing goggles to see the instruments a specialised lighting system is required,Lloyd (Ref 5). The spectral sensitivity of NVGs is maximal in the red and near infra-red. They are relatively insensitive to a blue-green colour and can be made totally insensitive by fitting a complementary red filter. If the cockpit lighting system is filtered to the correct blue-green colour, the displays and their reflections, will not be seen by the NVGs, but can be seen by the pilot around or under the goggles. The blue-green colour will result in a degraded visual acuity but this should not be significant. It is possible for the NVGs to read the instruments directly and this technique will be described later.

OCULAR HAZARDS

Impact

The ocular hazard from bird strike is minimal in current helicopters, due to their relatively slow speed, but this may change. The hazard from impact or collision is real and protection from the shattering of the large transparent enclosures is best provided by a dual polycarbonate visor system.

Nuclear Flash

Considering the sensitivity of most helicopters to over-pressure from the blast of a nuclear explosion, survival distances are relatively long. At survival distances the maximum ocular hazard is likely to be caused by low yield battlefield weapons, when the fireball forms within the blink reflex time (0.1 seconds). This hazard can be subdivided into retinal burns and flashblindness both direct and indirect.

A retinal burn is most likely to occur at night with a dilated pupil. By day, at most survival distances, the small pupil and blink reflex should provide adequate protection, unless the aviator resisted the blink reflex and stared at the fireball. At night a burn could well occur within the blink reflex time.

Should the power density at the retina be insufficient to cause a burn, it would almost certainly still be sufficient to bleach the photopigments in the area of retina affected, resulting in a glowing after-image. It may not be possible to see through this after-image for long periods, extending to minutes. It is unlikely, at survival distances, within the blink reflex time, that the after-image would subtend large visual angles and the visual decrement would not be significant unless the foveal region was involved. Direct flash-blindness is a problem by day and by night and protection is difficult, Vos (Ref 6).

The major hazard to aircrew is indirect flashblindness which is caused by viewing light from the fireball reflected by large structures such as clouds and by light scattered within the eye and the atmosphere. In this event the whole retina is flooded with light and all useful vision may be absent for a period of many tens of seconds. The situation is similar to entering a darkened auditorium from sunlight. It would compel the pilot to ascend for safety and thus risk destruction by enemy fire. Indirect flashblindness is usually only a problem at night, as by day the small pupil and light adapted state of the retina prevent a significant decrement to vision.

Protection is mandatory and many solutions have been proposed ranging through monocular eye shields, explosive shutters, fixed filters, canopy blinds and photochromic visors. The only solution which appears to give adequate protection, without an unacceptable visual penalty, is the electro-optic shutter Lead Lanthanum Zirconate Titanate (PLZT), Tredici (Ref 7).

PLZT is an opto-ceramic which has the ability, when electrically activated, to rotate the plane of polarised light. When sandwiched between two polarisers with their planes of polarisation at 90% with respect to each other, it is able to function as an optical shutter. In use, the light from the fireball is polarised by the first polarising filter so that it is at 90° to the plane of the second polariser; light is thus profoundly attenuated by the second polariser. When the PLZT is activated it rotates the light from the first polariser through 90° so that it is now freely transmitted by the second polariser. On sensing a flash, by a photo diode, the PLZT is switched to the deactivated condition and attenuates the light. As the fireball decays the PLZT is gradually reactivated to permit normal vision. The major disadvantage of the device is the low luminous transmittance in the open state, approximately 20%, and the consequent degradation of night vision. The device requires infra-red absorbing filters, a photo diode to sense the flash and miniaturised electronics to operate the PLZT (Figs 6 & 7).

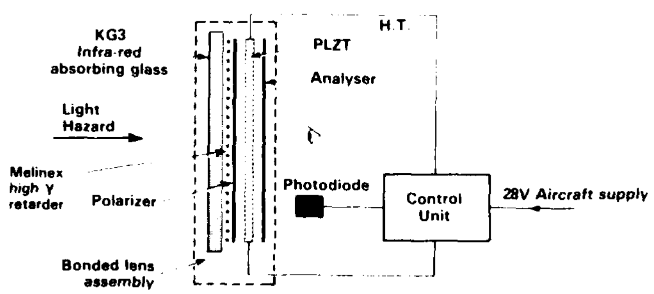

Figure 6. Schematic of PLZT bonded lens assembly (courtesy of Plessey Research (Caswell) Ltd.)

Figure 7. Prototype PLZT goggle with aircrew respirator No 5

Chemical Warfare Agents

Many of the agents used in chemical warfare can cause profound ocular effects in addition to their lethal action. The agents that could be used can be subdivided into Nerve Agents, Vesicants, Harassing Agents and Hallucinogens of which the most important are the Nerve Agents, Brennan (Ref 8).

Nerve agents are organo-phosphorus compounds which are potent anti-cholinesterases. They prevent the deactivation of acetylcholine by blocking the activity of anticholinesterase. In the eye, the prolonged action of acetylcholine causes an accommodation excess by over-activity of the ciliary muscle and an intense miosis. The small pupillary diameter causes a reduction in the light flux reaching the retina but also produces an increased

depth of field, nullifying the induced myopia caused by the accommodation excess. The reduction in retinal illumination can cause difficulties with night flight. The retro-bulbar and supra-orbital discomfort associated with exposure to anticholinesterases may cause difficulties in flight both by day and by night. Protection against these agents is essential and (Fig 8) shows the Aircrew Respirator NBC No. 5 (AR5) with its associated protective clothing and portable ventilator. The respirator completely envelops the head and is continuously ventilated with NBC filtered air. This device, which is in service with the Royal Air Force and Royal Navy, can be worn under current aircrew protective helmets and permits normal visor operation.

Figure 8. Pilot wearing AR5 respirator with portable ventilator and NBC protective clothing

Lasers

These are electro-optic devices which can produce narrow, collimated, coherent monochromatic, intense beams of light. They are able to operate in pulsed or continuous modes. In the pulsed mode, the duration can be extremely brief lasting nano seconds (10^{-9} s) when "Q" switched or even pico seconds (10^{-12}s) when mode locked or relatively long lasting milliseconds (10^{-3} s) when operating in the normal mode. Lasers exist which can emit with an immense diversity of wavelengths from the near ultra-violet to the far infra-red. They are used in military aviation primarily for ranging, guidance and target illumination. The neodymium, gallium arsenide, and ruby lasers, emitting at 1060 nm, 850-900 nm, and 694.3 nm respectively, are currently those most widely used.

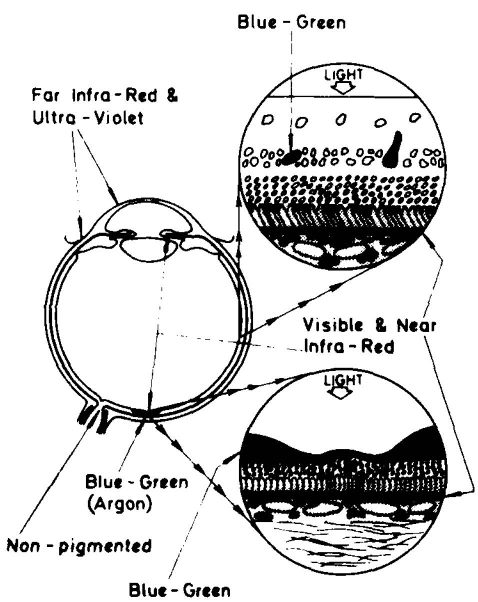

Figure 9. Wavelength band specificity of ocular absorption sites.

Given sufficient power all biological tissues are at risk. The eye, however, is at special risk as although it is only adapted to perceive electro magnetic radiation in the very narrow band from 400-780 nm, it will refract light from 400-1400 nm, bringing the long ultra-violet to the near infra-red radiation to a focus on the retina. The optical gain from cornea to retina may approach 4.5×10^5. Outside the band 400-1400 nm ocular tissues become progressively opaque and the energy is absorbed by the external tissues such as cornea, conjunctiva, sclera and skin. With the diversity of wavelengths at which lasers emit all ocular tissues and the adnexa are at risk (Fig 9).

Stanag 3606 - "Evaluation and Control of Laser Hazards" classifies lasers into four classes of increasing hazard. Most military lasers are class 3 or 4. Class 3 lasers emit radiation which is hazardous to view either directly or by specular reflection. Class 4 lasers exceed the upper limit for output power for Class 3 lasers, and may also produce hazardous diffuse reflections.

It is essential that all aircrew exposed to the beams of hazardous lasers be provided with suitable filters against the wavelength(s) from which they are at risk. Protective eyewear should comply with a specification such as the European Committee for Standardisation CEN/TC 85/WG 3 (Eye-protectors against Laser Radiation). It must be designed to offer the widest possible field of view, to be comfortable for long-term wear, to incorporate or allow the wearing of corrective lenses, and to be adequately ventilated to preclude misting. The filters should be of a high optical quality with the maximum luminous transmittance in both photopic and scotopic modes but weighted preferably to the CIE photopic luminosity curve. There should also be the minimum interference with colour discrimination.

Spectacles can be provided with side shields to prevent the ingress of unfiltered light but the loss of lateral field of view may be more hazardous than the laser itself, when used in flight, and should be omitted.

The best form of protection for aircrew, if feasible, is to replace a glare or impact visor with one providing laser protection. Dynamic devices such as the PLZT shutter, with a closure time measured in micro-seconds (10^{-6} s), are too slow to provide protection against the very brief pulses emitted by a "Q" switched or mode locked laser.

An ideal filter would only absorb the wavelength(s) at which protection is required and would transmit freely across the remainder of the visible band. Such filters can be provided using reflective dielectric coatings. These filters are expensive, fragile and their optical density (OD) varies with the angle of incidence of the laser beam. Absorption filters providing protection in the visible band are usually highly coloured and of a low luminous transmittance. If protection is only required against lasers operating in the near infra-red, this can be provided with ODs varying between 3 and 7 at the Neodymium wavelength (1060 nm). The luminous transmittance could be in excess of 60%, together with minimal colouration, by adopting filters in a glass or a glass laminate. It is difficult to provide such protection in plastics without using dense and highly coloured absorbing pigments.

OPTICAL AIDS

Night Vision Goggles

NVGs are the most widely used visual aid in helicopter operations. They permit night-time flight under starlight luminances or less, when they incorporate third generation tubes. The majority of NVGs are self-contained, lightweight, compact binocular devices which are attached to the helmet by a "break away" mount which also permits rapid elevation and removal. Each ocular consists of an objective lens with a nominal 40° field of view (FOV) and a relative aperture of f1.4 or wider. The photons collected by the lens are focussed onto the image intensifying tube where, by means of electron multiplication, the dark external scene, as viewed on a phosphor screen, is bright and easily visible. The erect monochromatic image is viewed through collimating optics at unity magnification. The NVGs operate in the visible and near infra-red spectral regions.

The major problems, encountered with the use of some NVGs, have been related to their limited FOV, resolution and contrast of the display. High resolution at low contrast has been found visually inferior to a high contrast and a lower resolution (Fig 10). It will therefore, be of value to measure the modulation transfer function of NVGs at the spatial frequencies of importance to vision (2.5-25 line pairs per mm). The depth of field of the goggles is of great importance on landing. Lenses with a very wide relative aperture, for extra light gathering (f1.4), may well cause difficulty close to the ground when texture is out of focus and blurred. Eye relief has been found to cause problems in attempting to integrate NVGs with respirators, when FOV has been still further limited.

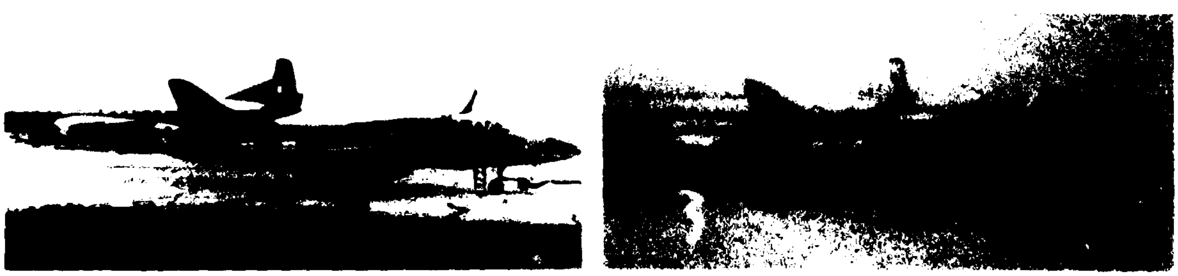

Figure 10. Comparison between a daylight scene as perceived by the naked eye and the scene as viewed through NVGs, with generation 2 tubes, under simulated starlight conditions.

Reading instruments, maps or charts is possible by a variety of methods. These include focussing the objective lens, bifocal designs, and look around models. It is also possible with red filtered goggles and complementary blue-green cockpit lighting systems to view the instruments directly. This is achieved by placing small positive lenses, with the correct power, directly onto the NVGs objective lenses, first removing the appropriate area of red filter from the centre of each of the objectives, Barrett (Ref 9).

An NVG under development is one in which the phosphor images, produced by the intensifying tubes, are projected onto twin plastic combiner plates sited in front of the user's eyes. This permits "see through" vision of instruments or the outside world with the intensified imagery superimposed, it also allows the addition of symbology (Fig 11).

Figure 11. Prototype night vision goggles with twin combiner plates (courtesy Marconi Avionics)

Visually Coupled Helmet Mounted Sights and Displays

Visually coupled systems are comprised of three elements. A helmet mounted display, which may vary between a simple sight and a hybrid presentation of the external scene. A means of sensing the pilot's direction of gaze by monitoring helmet position, using electro-magnetic or optical methods, and a weapon system, preferably with a "lock on" facility, or sensors slaved to helmet movement.

A basic sight, or a sight combined with alphanumerics is normally derived from a light emitting diode (LED) matrix. The red light emitted by the LED array is directed through a prism which folds the light into the space available and corrects optical errors. The rays of light from the prism are directed onto a dichroic visor coating, in a collimated form (Fig 12). Thus, the pilot can see through the combiner with LED derived information overlaid on the external scene and appearing to be at infinity. This information is only presented to one eye, the other eye having an unimpeded view of the world. The display is bright and easily visible. Under conditions of high ambient illumination the outer tinted visor can be lowered to increase contrast. These simple LED systems are generally without visual problem. The differing density presented to each eye has not been found to cause problems with spatial projection (Pulfrich Effect). In use, the pilot is frequently unaware of the monocular nature of the display.

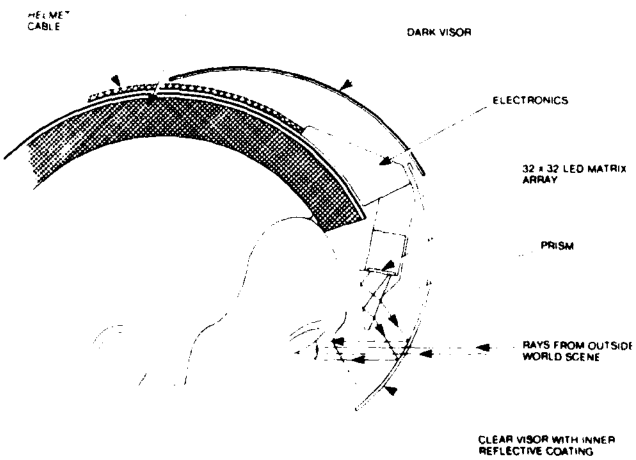

Figure 12. Schematic of helmet mounted display (courtesy Marconi Avionics)

Cathode ray tubes (CRT) displays of the real world, are presented to the pilot in a collimated form by a miniaturised tube and, usually, a see-through combiner attached to the helmet. The CRT can be driven by a low light television camera (LLTV) which can incorporate zoom optics to provide a wide FOV or a magnified view of a target. The system offers potentially higher quality imagery than NVGs, to which symbology may be added. In addition the CRT could be driven by variable magnification long wavelength infra-red sensors such as the

forward looking infra-red (FLIR). It is theoretically possible to produce a hybrid LLTV/FLIR picture.

In operation, problems have been associated with some of these displays,Laycock (Ref 10). As the CRT image may be so dissimilar to the real world, as seen by the other eye, fusion of the two becomes difficult or impossible. Attention may be devoted to one or switched between the two according to variation in image contrast or interest. Although attention may be devoted to one image only, that image may well be degraded by the competing image,Laycock (Ref 11). It may be preferable to close or shutter the left eye and devote attention solely to the mixed image as seen by the right eye. At night the problem of binocular rivalry is diminished, but problems have been encountered in disregarding the display whilst reading instruments. The pointing accuracy of the sensor is important if external lights are not to appear doubled.

The optimum solution could be a pilot using unaided vision by day and NVGs by night, perhaps changing to a wide FOV FLIR in poor meteorological conditions. The weapon aimer could either adopt zoom sighting systems by day or a head down or helmet mounted display at night, incorporating a narrow FOV FLIR/LLTV display. The system could incorporate a mutual pointing device so that either the pilot or the weapon aimer can direct the attention of the other to targets in his FOV (Fig 13).

Figure 13. Helmet target acquisition and designation system (courtesy Ferranti Electro-optics)

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DISORIENTATION IN HELICOPTER FLIGHT

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SUMMARY

The term "disorientation" is usually confined to disturbances of the pilot's perception of his position in space. In this paper the term is used in a broader sense, i.e. for any incapacity of the pilot to maintain a safe path of flight due to inadequate, erroneous or disregarded visual cues. The psychological process of visual perception will be discussed especially with regard to the differences between optical stimuli from the surroundings and their subjective perception by the individual. Special emphasis will be placed on the fact that the human brain is an active organ and not just a mirror reflecting the visual stimuli from outside. To minimize disorientation the aviator should have in mind the basic programs according to which the brain processes visual stimuli, visual configurations which are prone to elicit visual illusions, and means to prevent the onset of disorientation.

I. INTRODUCTION

Not only is disorientation in helicopter flight a problem, but the term disorientation is a problem in itself. When searching through the literature it becomes apparent that the term disorientation is used in a rather restricted sense, namely as a disturbance of the pilots perception of his position in space.

As early as 1918, Jones (2) stated, "Without functioning internal ears, it is impossible for an individual to be a good birdman. In order to preserve the wonderful accuracy necessary in controlling such a delicate mechanism as the flying machine, he relies preeminently on his ear balance...."

This is not only wrong, but unfortunately from these early days on, disorientation has always seemed to be associated with a state of confusion concerning the subject's true position in space (4, 6, 13, 17), whereas practically every aviator knows orientation errors which are not only caused by an incorrect or "seat of the pants" impression of the attitude, position, or movement of the pilot and/or aircraft relative to the horizon or other stable reference as most authors put it, but which also occur in contexts not associated with illusory perception of the attitude or motion of the aircraft. Such a spectacular disturbance of perception as the "break-off"-phenomenon is not necessarily accompanied by spatial disorientation in the sense mentioned before. Though the aviator experiences a feeling of unreality and detachment which means that his orientation of self with respect to the aircraft, or self with respect to the earth datum is disturbed, he may nonetheless perceive motion and attitude of his aircraft quite correctly (3).

More often than not a pilot confronted with the term "spatial disorientation" will associate it with geographical disorientation, with the idea of being "lost". Yet at least one author (18) expressively does not consider navigational errors true disorientation. Probably the author cannot imagine the situation where an aircraft is flying in perfect attitude relative to the horizon with the pilot being completely lost and neither heading indicator nor landscape around him making any sense to him, while simultaneously he feels a wave of nausea sweeping over him as he realizes that he is in big trouble.

It is in support of this opinion when Clark (5) includes geographical disorientation : "Geographical disorientation involves incorrect orientation to compass points or places and was frequently reported by all groups (pilots) on the check list. Another problem related to geographical disorientation is found in difficulties which pilots sometimes have in recognizing familiar landmarks. Approximately one quarter of the pilots reported this experience which is known by the technical name of jamais vu ("never seen")".

It has been suggested that one should differentiate between spatial disorientation, visual restrictions, and visual illusions. In which case visual illusion is defined as the perception of something objectively existing but in such a manner as to cause misinterpretation of its actual nature (19). But again the consequence of such an illusion may be disorientation. On the other hand a pilot in perfect control of the aircraft and without any doubt about what he sees in front of him may fly straight into an obstacle which he has not seen. There are several reasons why it is possible not to see an object which for another obverser in the same situation may be clearly visible. Is it justified to label such an accident as a cause of visual illusion, or shouldn't we rather say that the pilot was disoriented in the meaning that he didn't perceive his surroundings correctly?

Obviously the topic "disorientation in helicopter flight" encompasses more than just a state of confusion concerning a pilot's true position in space.

It seems that at the beginning of a process of disorientation there is always a visual cue which is either inadequate or erroneous. It is inadequate when the sight is degraded by sun glare, dazzle, adverse meteorological conditions, featureless terrain, water lacking wave texture etc. It is erroneous when pilots feel that their aircraft is moving as they look at a wave pattern on water or long grass generated by the ground effect of the rotor etc. (13).

In order to deal with the problem of disorientation in helicopter flight it is therefore necessary to gain an understanding of what visual cues the human brain extracts from the visual stimuli it receives from the world outside and what possible causes for disorientation originate from there.

Another word has to be added to the expression disorientation in "helicopter" flight. Practical experience has shown that there is no special disorientation in helicopters which is different from the disorientation which may be experienced in fixed wing aircraft. Even the break-off-phenomenon which has been reported by pilots flying in excess of 30.000 feet altitude was experienced by helicopter-pilots flying in altitudes not exceeding 5.000 feet (3, 6).

Even if there is no difference between disorientation in helicopters and fixed wing aircraft there is one addition to be made for helicopters: as modern warfare dictates flying at treetop-level and below this level the helicopter-pilot finds himself in an environment where he is practically surrounded by obstacles among which he has to maintain the highest possible flying speed. This makes the quick detection of obstacles a vital task. Yet time and again pilots tend to overlook obstacles even when they stand out in broad sunlight. Therefore, disorientation is not only the consequence of visual cues that are inadequate and erroneous but of cues which are disregarded completely for some reason or other.

II. PERCEPTION OF REALITY

The eye is often compared to a fotografic apparatus. There is a basic resemblance indeed as far as the construction of the eye is concerned (8). And it seems that accident-investigation-boards are occasionally quite happy with this explanation of eye functioning because it leaves them simply with the task of finding out whether optical stimuli which may have carried important messages could have reached the eyes of the pilot. Once this question is answered in the affirmative it is up to the pilot to explain why he didn't act accordingly - if, of course, he is still in a condition to be asked such a question.

There seems to be little doubt that the image which is projected on the retina is truly transmitted to the brain in all its details, and that somewhere in the brain our optical surroundings are represented by means of some physiological process about which we have only a very vague idea, but which nonetheless is perfectly correlated to what is going on outside. Accepting this as true, then, of course, the question: "Why didn't he see it? It was right in front of him!" would be difficult to answer. Apparently what happens in the optical centre of the brain is somewhat different from what is projected on the retina. To illustrate this one merely needs to consider a simple everyday experience.

1. Perceptional Threshold

Pilots are familiar with the phenomenon that during night flying lights which can be seen far off on the ground tend to go on and off at random even when it is certain that they are not concealed by some obstacle. Here is a case where the image on the retina is not the one in the brain. In order to reach the brain the visual stimuli from the distant light spots have to overcome what is called a sensory threshold. This threshold is not an individual constant but varies all the time. It varies for instance with the degree of fatigue and various other factors. It would not be enough to ask in an accident investigation: was the view of a certain visual signal unobstructed? One would also have to ask: was it strong enough to overcome the pilot's visual threshold? And this question would not be a general one, but would have to refer to the given moment. In this example a visual stimulus actually hits the retina but cannot get through as a result of a raised visual threshold. There is yet another possibility why a visual stimulus which has found its way into the eye may not be perceived.

2. The Blind Spot

On the retina there are many more photosensitive cells than there are opticle nerve fibres. Approximately 100 rods or cones are bundled together into one nerve fibre. So, right at the beginning of the process of perception there is already some evidence that the physiological stimuli and the physical stimuli are not perfectly congruent.

But there is a much more important problem connected with the retina. It is well known that the optical nerve fibres leave the eye bundled together in an area known, on account of the absence of photosensitive cells, as the "blind spot". We hardly ever realize that we should actually see two black holes in front of us. The fact that we don't see them is due to our brain assuming that what we would see if the vision were not obscured by these black holes would be the same as what is directly adjacent to them. Therefore, the brain quite innocently completes our perception of the world outside with details it does not actually see. This fact is so well known that we tend to forget not only that the naive belief that the image in the brain is directly related to what is on the retina is only partially true, but also that the optical centre of the brain is not just a mirror reflecting the world outside but rather an active organ which produces visual impressions by itself. To what extent the brain does this can easily be observed.

3. Constancy Phenomena

a. Constancy in size

Two objects of the same size but of different distance to the observing eye will cast images of themselves on the retina which are the smaller the farther away they are. If we hold both our hands in front of us but in such a way that one is approximately double the distance from our eyes than the other, then according to the rules of geometric optics the image of the more distant hand on the retina is only half the size of that of the other one. When we make this little experiment we nonetheless perceive our two hands as having exactly the same size they always have. Our brain of course knows that both hands are more or less the same size, so it is not deceived by the image on the retina. But what happens when we see something which is not known to our brain? In such a case we will either be disoriented with respect to the size or the distance of that object or both. This build-in constancy mechanism not only functions with regard to size.

b. Constancy of shape

When you look at Fig. 1 you perceive an oval. Exactly the same oval appears in Fig. 2 with

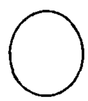


Fig. 1

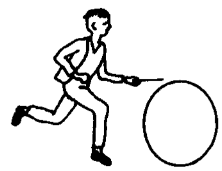


Fig. 2

the only difference that now a child is playing with it. Of course you know that children usually do not play with ovals but with hoops, and they are round. So that's what you see! Naturally this constancy of shape is a great help in dealing with all the optical confusion around us. Our brain knows that a hoop is round no matter from which angle we look at it. This constancy of shape is fine as long as our brain knows what we are looking at.

There is yet another constancy-mechanism build into our brain.

c. Constancy of brightness

A heap of coals is black and a sheet of paper is usually white. It doesn't matter whether we look at the coals and the paper in a dark cellar or in the open in bright sunshine: the one is black and the other is white. Though it can be shown that the heap of coal in bright sunshine reflects almost or even more light than the white paper in the dark cellar. Still our brain knows which has to be white and which black.

This constancy of brightness is the reason why we need an exposure meter along with our camera and why it takes some pilots so long to turn their position lights on when it is already quite gloomy around them.

Conclusion

It should be clear from these few examples that the reality we perceive is not the reality of the world outside but rather the "reality" within our brain. This is in no way dangerous as far as we confine ourselves to the speed of a pedestrian and remain in familiar surroundings. Actually, under these conditions, the constancy phenomena have their merits in as much as they help us to impose order on the confusion of optical stimuli.

To do this our brain has to be active and work on those stimuli, and while doing so it exhibits another disconcerting habit: it does not tell the individual when it is displaying original and when, let us say, "refined" optical data. We have to accept what perceptions our brain offers us. Occasionally somebody finds out the hard way that what his brain is making him perceive is not what his eyes see.

III. VISUAL DEPTH PERCEPTION

As nature has provided us with two eyes depth perception seems to depend basically on three physiological mechanisms, namely
- convergence
- disparity
- accomodation

However these three mechanisms function only up to a distance of approximately 10 meters while the aviator is usually concerned with the assessment of much larger distances. Of course it is possible to judge distances in access of 10 meters but this is no longer done by means of physiological mechanisms but by depth cues which trigger off psychological programs stored in the brain. From the previous chapter we know that caution has to be used once the brain starts working on visual cues. Therefore we have to know what makes us perceive depth once the physiological mechanisms no longer function. (For more detailed informations see 7, 12.)

A. Innate Factors of Depth Perception

1. Crossing over:

In Fig. 3 we see a cross and a rectangle overlapping it. This is a statement which is of course not justified because we know quite well that the two figures are two-dimensional. Therefore we could as well say that the cross is overlapping the rectangle as the two figures are in one plane anyway. However the impression that the rectangle is in front of the cross is quite convincing.

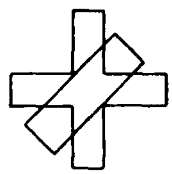


Fig. 3

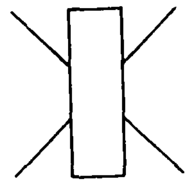


Fig. 4

2. Masking:

Let us look at Fig. 4 where a cross is covered by a rectangle. Again that is not what we see but what our brain thinks it should see. Because on our retina only a couple of lines from a two-dimensional sketching are projected. On closer inspection there is not even a cross but the main point is that in this and the previous figure our brain readily produces an impression of depth when given a few lines.

It is for our purpose not necessary to go into any theories why this is the case. It is only necessary to point out that our brain is provided with an innate program for depth perception, and it will perceive depth once certain visual cues are given, no matter what the objective configuration in the world outside may actually be. This is especially true when the visual conditions are bad and the surroundings are unfamiliar. Then it may happen that a pilot perceives objects or landmarks as being in the background whereas in reality they are actually in the foreground, which may occasionally have unfavorable consequences.

B. Depth Perception due to Experience

a. Size

3. Apparent size:

If we saw the landscape rise in front of us like in Fig. 5 and we didn't know what it was we would have some problems estimating the distance. If it were a heap of sand it would be close by. If it were a rock we would probably judge it to be farther away. The task became easier if we saw something standing close by the size of which is well known to us like a man. In that case it would be easy to decide that what we saw was some heap of dirt and we would even have a fairly accurate impression of the distance it is away from us.

Again it is clear that for this kind of depth perception we have to know what we are seeing and we have to know what size it has. It takes some time for the student pilot to gain this knowledge and even the experienced aviator once in a while meets with situations were he is not quite sure what he is actually seeing. How is he then to judge distance?

Fig. 5

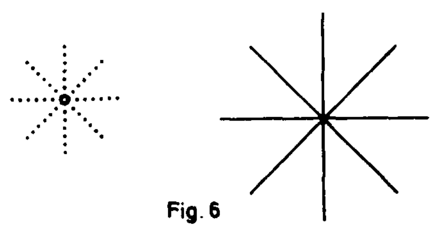


Fig. 6

4. Changes in size:

Let us assume we first saw the star in Fig. 6, having the size of the little dotted figure and than becoming gradually the size of the large figure. What would we think is going on? There are two possibilities: either we saw a star inflating itself like a ballon or what is more likely especially if there were no other visual cues we would see a star approaching from the distance.

The impression of motion in space became even more convincing if we knew what object it is and if we knew that it is solid and cannot change its size. This is the trick by which spaceships are made to dash through the infinity of space in movies like "Star Wars". But the aviator may not only encounter these impressions in movies, he may be confronted with them in reality, as a pilot reported who very nearly escaped a mid-air-collision with another plane approaching him head on at such a frightening speed that he froze for a moment at the controls only to find out in the next moment that he was being attacked by a model-airplane. What impressed him most was that in the moment he discovered the real nature of his opponent the perceived size of the plane shrank within a fraction of a second from that of a fullsized jet-fighter into that of a comparatively small model and it practically jumped forward because it was actually much closer than the imagined jet-fighter, that it was fortunately not, had seemed to be.

The conclusion from this is that the aviator should not only know what he sees but should also know what size the objects around him are. Disorientation is not only a problem of vision but of memory as well.

b. Motion

5. Relative motion:

From the last example it could be seen that motion of objects plays an important role in the perception of visual depth. As a rule it can be said that objects which under otherwise equal conditions move at different speeds are judged to have different distances from the observer. The quicker an object moves the closer it seems to be.

So, if for instance a jet and a helicopter pass in front of an observer in the same distance the jet will be judged as having passed closer. The same applies as far as altitude and speed are concerned: a helicopter-pilot who in circling around a confined area hidden somewhere in the woods and losing speed while he is occupied with figuring out the best way to fly the approach may, instead of increasing his speed, again unconsciously reduce his altitude in order to regain the same impression of speed he had before.

The same experience in reverse has been made by fixed-wing-pilots attempting a no-flap-landing. In such a case the approach speed is higher than usual, and this may lead to the pilot unconsciously adopting a higher glide-path than normal in order to maintain the same impression of speed over ground. The result may well be a rather rough touch-down.

c. Structure of the Surroundings

6. Atmospheric perspective:

Though we well know how painters create an impression of depth in their pictures it happens again and again that pilots are deceived by what is called atmospheric perspective especially while navigating, but also while trying to avoid obstacles. The term atmospheric perspective means nothing mor than the haziness of distant objects. Objects which cannot be seen clearly are assumed to be farther away than they actually are. Conversely, we all know how impressive it is, when after a prolonged period of haziness the sky clears and we have to relearn our estimations of distance. This is especially confusing for student-pilots while training tactical navigation.

7. Stereoscopic colours

For reasons unknow to us we associate colours with distance. From paintings we know that
- reddish, brownish and yellowish colours seem to protrude
  while
- bluish colours tend to recede

This last fact is by the way a mere coincidence with atmospheric perspective. As nature changes its colours according to the season for instance in autumn where reddish and brownish colours prevail the impression of distance may differ from those a pilot gets during wintertime especially when he is flying at low levels.

8. Contours:

Contours are the most important visual clues not only for the perception of depth but for perception in general. Plain one-coloured surfaces supply the brain with practically no information at all. The most dramatic loss of visual information happens when the pilot experiences the "white-out-phenomenon" which is well known and feared. It is usually the consequence of the rotor-downwash of a hovering helicopter over an area covered with loose snow. The pilot loses his orientation because his surroundings lose their contours.

Contours are usually provided by shadows. It is therefore a misconception to try to help a pilot during night-landings by illuminating the landing spot as brightly as possible. Even if he is not dazzled, mere brightness will not help him much if the lighting is not arranged in such a way as to cast shadows which give the visual field in front of him the necessary structuring for judging depth and distance.

On the other hand, contours cast by shadows may have their disadvantages in as much as the impression of depth which they generate may be deceptive in certain cases. A field covered with shell-craters may look totally different when the sun changes the direction of the shadows cast by the crater-walls. This may even lead to the impression that the craters have changes into humps.

Quite often landing-sites for helicopters are just lit by the headlights of one or two trucks. As these lights are rather low, even small and hardly perceptible humps in an otherwise flat piece of land will cast long shadows thus creating at least an uneasy feeling in the pilot as to whether he may touch down safely.

There is yet another aspect to be kept in mind when talking about the importance of contours for the perception of depth. Contours as it has been said are created by shadows or in more general terms by differences in brightness. In a mountainous area individual mountains will only be discernible as far as they differ in brightness and/or colour from their neighbours. Under hazy weather conditions mountains will not only lose their individual colours and take on an uniform grayish or bluish hue, they will also assume an equal brightness. If this happens even quite prominent mountains may become invisible as if they had turned into glass (Fig. 7).

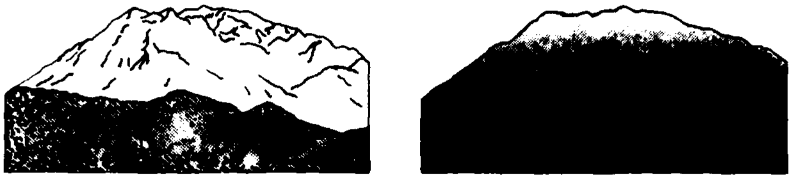


Fig. 7

Two mountains overlapping each other are clearly discernible as long as they differ in brightness. Once their brightness becomes equal, due to weather conditions, the mountain in front is no longer visible and becomes a potential hazard.

It is speculated that the crash of an Australian airliner in the Antarctic a couple of years ago was due to such an "invisible" mountain.

9. Linear perspective

Another prominent indicator of depth is linear perspective. Distance is judged by assessing the apparent convergence of lines which are known to be parallel. Though this seems to be more important for the fixed-wing-pilots as linear perspective can best be observed while approaching runways the helicopter-pilot depends on linear perspective as well when he is flying below tree-top level along wood-vistas. Under these conditions he may be prone to the same visual misconceptions as the fixed-wing-pilot approaching a runway (11), such as:

- the wider a wood-vista is the shorter it appears (Fig 8)

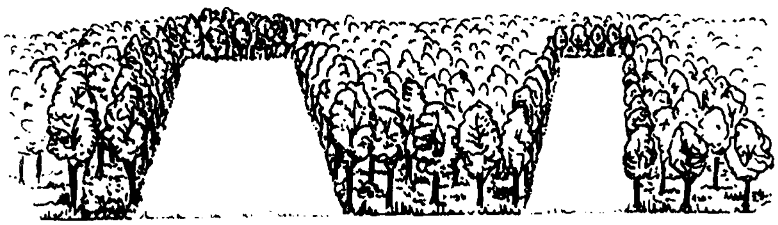


Fig. 8

Wideness of wood-vistas and apparent length

- it can also be seen from Fig. 8 that in the case that two vistas are situated side by side but differing in wideness they also produce an impression of having different elevation.

- particularly dangerous are those wood-vistas which have a hardly perceptible slope. As pilots flying under NOE-conditions judge their height above ground by looking as far ahead as possible and estimating the angle their line of vision forms with the surface, a gently upsloping surface will increase this angle and thus give the pilot the false impression of climbing. An instinctive correction of altitude without a cross-check of other visual cues may have under the conditions of NOE-flight disastrous consequences (Fig. 9).

Fig. 9

Perceived distance to the ground in a gently upsloping terrain

10. Texture of the ground

For the sake of completeness it should be mentioned that the texture of the ground also produces visual cues for the perception of distance. The length of a field may appear quite different according to whether it is snow-covered or freshly ploughed.

Conclusion

Depth perception is mostly a psychological process in as much as the brain does not check physiological parameters like the positon of the eyeballs or tension of eye-muscles but it assesses visual cues according to

- innate programs and
- experience.

Correct depth perception is only possible if the pilot knows what he is seeing. If he doens't then his brain will nonetheless tell him what it thinks is going on in front of him, and then he can only hope that his mental image corresponds to reality.

IV. PERCEPTION OF MOTION

The ability to perceive motion was developed by nature much earlier than any other visual abilities. It is of course much more interesting for any primitive animal to see motion in its surroundings, be it foe or prey, than to contemplate the scenery. As nature never discards anything which has proven to be useful, even the human eye still contains in the outer parts of the retina this old mechanism of perception. If moving visual stimuli excite this outer area of the retina nothing is seen but the eye moves in the direction of the stimuli. This leads to the theory that the retina can be divided into at least three concentric areas which serve different visual purpose. The function of the outer ring has just been discribed.

a. Focal and ambient vision

The inner and smallest part of the retina is needed for focal vision. It tells us what we see. The part adjacent to this is needed for ambient vision which tells us where we are. This division of tasks makes it possible, for instance, for us to walk, keep our direction and simultaniously read a book.

There is another difference between focal and ambient vision: the accuracy of focal vision is dependent on brightness while ambient vision, which just helps us to keep our direction while we move around, functions quite well at lower levels of illumination. This seems to explain why people tend to drive dangerously fast at night.

According to Leibowitz and Dichgang (in 1) bad focal vision at night gives the false impression that there are no obstacles ahead of the driver while ambient vision still enables him to stay on the road perfectly well. The net result of this over-confidence based on the immunity of ambient vision to lowered illumination and the consequences of degraded focal vision (dependent on brightness) is highway speeds which are too fast to permit adequate response to hazards on the roadway.

It is hardly necessary to add that this also offers an explanation for obstacle collisions of helicopters flying NOE in the twilight or under adverse weather conditions. Pilots should be warned that they can still find their way perfectly well while flying at low level when they are already no longer able to perceive obstacles clearly. The flying speed should be adjusted accordingly.

b. Illusions of Motion

Our ability to perceive motion is less impressive than the fact of the stability of our optical surroundings in spite of movements of the head. It is easy to understand that maintaining this stability is a tremendously complex task of our brain. Being so complex it can easily be disturbed. Therefore the aviator should be familiar with common illusions of motion.

1. Autokinetic phenomen

Probably the best known illusion of motion is the autokinetic movement of isolated light sources in the absence of other visual references. It is obviously due to the wrong interpretation by the brain of fatigue of the eye muscles.

2. Waterfall-Illusion

An illusion already known by the old Greek is the waterfall-illusion. If somebody fixates a waterfall for some time and then shifts his fixation point onto some uniform surface he will have an illusion of pure motion. "Pure" meaning that it is an impression of motion which is not related to a moving object. Now it will hardly ever happen to a pilot that he has to watch a waterfall just before he is going to fly. This illusion is mentioned here not because it is a potential reason for disorientation but because it is in favor of a perceptional theory which is otherwise of relevance for flight safety. There is evidence (15) that visual stimuli are processed by different channels. Each channel is responsible only for specific visual stimuli. There is supposed to be at least one channel for the perception of static objects and there are several

channels for the perception of motion. Even the perception of vertical and horizontal motion is processed by different channels. The informations from all these channels have of course to be coordinated perfectly by the brain.

When this coordination gets lost phantastic illusions will be the consequence. Exactly that is what happens when the brain is poisened by alcohol or drugs or stressed by fatigue. The relevance of having enough sleep and being sober for the prevention of disorientation is quite obvious.

3. Induced motion

The impression that the moon is moving through the clouds or the pier of a bridge is moving upstream or the train on the adjacent track is pulling out of the station when in fact the train we are sitting in is moving is called induced motion. One possible explanation for this phenomenon that objects seem to move which are known to be stationary and which is so convincing lies in the fact that it is always the smaller object in an apparently static surrounding which is perceived as moving.

Pilots may be prey to such an illusion as well. Just imagine a helicopter pilot who is in a stationary hover and whose mind is occupied otherwise. Suddenly he perceives a little APU on the ramp slowly moving away from his helicopter. The chances are that it is in fact his helicopter drifting away from the APU and that he is about to collide with something at any moment.

In flight there is always the possibility of being disoriented by apparently moving stars which are mistaken for position lights.

4. Inertia of vision

An intermittently flashing light can only be seen as flickering as long as the flicker frequency stays below approximately 30 Hz. This frequency may be higher in case of a very bright light or lower if the observer is fatigued. Flicker discrimination can therefore be used as a measure of fatigue. But what is more of interest for the aviator is the fact that a flicker frequency of roughly 10 Hz can generate the impression of motion and of colours. Especially the helicopter-pilot may be subjected to such critical flicker frequencies for instance when the sun is shining through the rotor.

What is even more important is the observation that the flicker frequency produced by rotors or even slowly turning propellers can serve as a photic stimulus and engender a convulsion in a susceptible individual. This phenomenon has been termed "flicker vertigo" (4).

5. Apparent movement (Stroposcop movement)

One should not get the impression that all visual illusions are detrimental to a safe course of flight. During night-approaches we take advantage of the perceptual system's difficulty in coping with intermittent stimuli in a short time scale when we perceive a light-arrow flash towards the touch-down point, while we know well that all we see are approach-lights which are turned on and off in a certain sequence.

We call this phenomenon apparent movement. When a brief stimulus is followed by another stimulus after a short interval of time and within a short spatial interval, there is an impression of movement from the position of the first to that of the second. With several stimuli in the proper sequence a smooth, realistic movement can be achieved.

V. SEEING AND PERCEIVING

When summing up what has been said thus far it should be obvious that the pattern of visual stimuli which is cast on the retina is not always what we actually perceive. It is our brain which decides what visual stimuli are selected for further processing and it is our brain which finally comes up with a perception which is not necessarily congruent with what is going on outside. The dangerous thing is that the visual center does not mark its perceptions with a rating on how sure it is that what it perceives is the reality outside. It always comes up with a clearcut solution to the puzzle of visual stimuli. That is what makes visual illusions so convincing. The brain never comes up with a message like: "This is what I have actually [illegible] and this is what I make of it". Of course in every-day-life this would be unnecessarily complicated and when having to survive in a prehistoric world full of wild beasts the brain had to be pretty quick in perceiving any potential danger, and even if our ancestors ran away more often than was actually necessary due to visual disorientation no real harm was done. But it would have certainly been detrimental to the human race if it had developed a brain which would produce messages like: "At the moment I don't have sufficient visual information, let's wait until I have gathered some more". In order to come to a quick solution the brain relies on innate visual programs for structuring all the visual stimuli and on experience to give them a meaning and to supply those which seem to be missing. Therefore we have to differentiate between seeing and perceiving.

A. The Perception of Visual Elements

The main problem when trying to unravel the reasons for a visual misperception is that we have to reconstruct bit by bit what the individual who was deceived saw. But putting bits together will only give us clues as to what the individual saw and not what he perceived. Because we don't perceive our visual surroundings as a sum of visual elements but as a whole or a totality or, for those who are familiar with that psychological term, as a "Ganzheit". What

does that mean. Look at the simple example in Fig. 10. We see four lines, but we perceive a square. We even see a square when there are really only four separate lines as in Fig. 11.

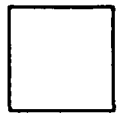
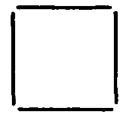
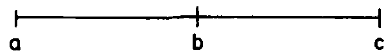
Fig. 10


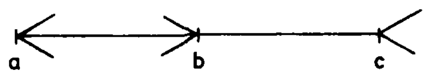
Fig. 11


It is actually rather difficult to look at just one line and disregard the others, because without the other lines one single line would lose the significance it has when it forms one side of a square. This also means that each visual element is influenced in its perception by all the other visual elements which form the whole picture. This is the explanation for most visual illusions. However, the practical importance of illusions should not be overestimated; most perceptual environments are too rich in information to give rise to illusions (16). Here is another example:

Let us suppose for some reason or other helicopters have to hover through a narrow gap. In order to facilitate this job for the pilots somebody has painted marks on the ground like in Fig. 12

Fig.12


Mark b is mid-way between marks a and c. Hovering directly over mark b will provide enough rotor clearance to the right and left. Unfortunatley there are quite a few rotor collisions on the right side. Are the pilots not capable of hitting the mark in the middle? On closer investigation we find that Fig. 12 is not complete. What was actually painted on the ground looked like Fig. 13. Now it has to be pointed out that the

Fig.13


visual elements, that is the distance from a to b and from b to c, have not changed. But what has changed? The whole of the visual field has changed and therefore the perception of the elements has changed as well. (For more details about visual illusions as a probable cause of aircraft accidents see also (19)).

We find this phenomenon that single elements are influenced by the whole of the surroundings in other areas of perception as well. The same temperature of 20° C may be warm when we come in from outside or cold when we step out of a hot bath. Such a misjudgment due to previous experiences is also known as the Gulliver-Phenomenon: Gulliver was amazed about the size of human beings after he had lived for so long in Liliput. Before blaming a pilot for having misjudged something one has to ask two questions:

1. What did the surroundings look like in which the object was embedded?
2. What previous experiences had the pilot had with the object in question?

As investigation-boards tend to think more in technical than in psychological terms they are more interested in elements than in the whole. They would probably take out a yard-stick, measure the distance in Fig. 13 between the marks a, b, and c, find that they are equal and would write in their report that the pilots had all the necessary information to avoid collisions with obstacles to the right or to the left.

In order to understand visual disorientation one has also to understand that our visual surroundings are a visual totality which is more than just a sum of its elements and that each element is influenced by all the other elements. That is the reason why perception is different from the mere pattern of visual stimuli.

B. Factors of Perception

In what way do perceptions differ from the mere pattern of visual stimuli on the retina? What does the brain add to those visual stimuli to transform them into perception?

1. Stimuli and sensation

The same stimulus may evoke quite different sensations. It may be repulsiv or attractiv. The colour red is in the Western hemisphere usually associated with traffic lights while in the Eastern hemisphere it is the colour which stands for a better future. One has to remember that the mere visual stimulus "red" contains neither of these emotions. They are added by the respective brains. It is necessary to know that perceptions are always associated with emotions. Therefore individual reactions to the same stimulus can be quite unexpected.

Even in the same individual emotions may change so that one day he likes the colour red and the next day he hates it. And while hating it the individual may tend to disregard it. To put the point into straightforward aviation terms:

A pilot has to be in the mood to perceive a warning light or an obstacle!

On the first sight this last statement seems to be rather exaggerated. But isn't it an almost universal experience that we tend to overlook, let us say a dentist's name-plate even if we have an appointment with him, or that, while consulting our diaries, we "fail" to notice a disagreable date? It would certainly not be difficult to find lots and lots of similar examples and in many of these examples it could probably be proved that the object in question was actually seen but not perceived.

Even if such cases of "psychological blindness" are rare in aviation they have to be taken into account in particular in those cases where everybody including the pilot himself is flabbergasted that such an obvious obstacle or such an obvious instrument or indication was overlooked.

But even when the pilot sees what he is supposed to see and realizes it he still may not perceive it in its proper shape or size but rather distorted by his emotions. From a socio-psychological experiment it is known that children of lower class parents tend to overestimate the size of coins. How often will the emotional state of a pilot, his unsatisfied needs and drives or his motivation lure him into false perceptions of his surroundings? Disorientation in pilots may be more often than not more a question of the psychological state of the pilot at the time of the incident than anything else.

2. Structuring

Just one look at the sky on a moonless, starlit night reveals to us better than any experiment could do, that our brain immediately organizes the confusion of visual stimuli which flood our eyes. We have to remember that the constallations we see are only present in our brains and not in the sky. There are quite a few laws according to which our brain structures our visual surroundings (12) but it would go too far to mention them here. Quite a few of them are relevant for camouflage, because a really clever camouflage does not just hide objects behind screens etc. but integrates the object which has to be hidden in such a way into the surroundings that it becomes part of another visual structure. Camouflage would be much more difficult if we perceived by means of putting together visual elements. But as we perceive visual structures or totalities we can easily be deceived when the detection of a single visual element is essential.

This explains orientation errors during low level missions when turning points are missed because the barn or the bridge or whatever the pilot was looking for fitted so well into the structure of the landscape that as visual elements they could have been discriminated only if the pilot knew what they looked like and where exactly they were situated.

3. Spontaneous Restructuring

As it was said before the brain is usually quite sure about what it perceives and comes up with a clear-cut perception. But occasionally it receives visual stimuli which are so ambiguous that more than one solution to the visual puzzle is possible. What does the brain do in such a case? One can find it out if one looks at Fig. 14.

This sketch of a cube is ambiguous in as much as it is not clear whether the corner marked with a small circle is in front or at the back. Instead of leaving the solution open until more visual cues are found to decide for sure which perception of the cube is the right one, it immediately comes up with one of the two possibilities, but then if one continues looking at the cube it all of a sudden restructures the visual stimuli into the perception of the other possibility and it keeps changing the perception of the cube for as long as we look at it, approximately at a rate of one change every 10 - 15 seconds.

This observation is important for two reasons: it shows in a striking way that perception is an active process of the brain and that one has very little influence on the outcomes of that process. Even if one knew that neither of the two solutions was correct, that in fact Fig. 14 was just an arrangement of meaningless lines it would need a strong mental effort to overcome the impression of a three-dimensional cube.

A pilot flying under poor meteorological conditions in unfamiliar surroundings may experience this phenomenon of a perception restructuring itself at a much faster rate than once every 10 - 15 seconds if he is for instance trying to find out whether it is a church or a factory that he sees in front of him. He even may experience the first symptoms of motion sickness during this perceptional process.

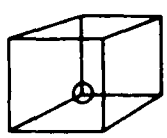


Fig.14

Fig.15

4. Law of Pregnance

If somebody has to remember certain objects he has seen and is asked to make sketches of them some time later one will observe that these sketches differ in a specific way from the original. This is not only a question of the individual's ability to draw such sketches. If one looks for instance at Fig. 15 there will certainly be no difficulties in reproducing this sketch. But what

most people will do is to produce the "T" indicated by the dotted line in the figure. Without that dotted line hardly anybody would have noticed that the horizontal line is not quite perpendicular to the verticle line but oblique.

This is an example that the brain not only fills in visual gaps, as has been explained before, but that it also "corrects" the visual impressions and converts them into shapes which are more regular than they are in reality.

Thus under certain conditions, especially when the pilot is quickly scanning the instrument-pannel, it may happen that the beginning deviation of a pointer, especially when it is deviating from an exactly horizontal or vertical position, is seen but not perceived according to this tendency of the brain to correct visual impressions from objects not having a regular shape. Thus it is possible that pointers may be way off the mark they should normally indicate before their deviation is discovered, because the beginning of their deviation was not noticed. This may also start or aggravate a state of disorientation in the pilot.

5. Figur and Ground

The story is well known in which a pilot hits the only tree standing in the middle of a wide plain. There are of course several possibilities why such an obviously stupid accident may happen. In any case in order to avoid the collision the tree must catch the pilots attention. The question is how does an object which otherwise stands inconspicuously in our surroundings catch our attention.

If one looks at Fig. 16 one can perceive either two faces looking at each other or a cup. What we perceive depends on what parts of the sketch are perceived as figure or figures and what parts form the background. The figure catches our attention while we tend to ignore the background.

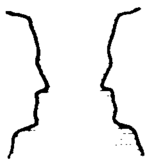


Fig.16

Fig 17

In order to avoid that single tree it is necessary that this tree becomes a figure in front of a background in the perception of the pilot. This may occasionally prove to be difficult because of the background. In Fig. 17 a small wood and an isolated tree in front of it are sketched as it may be seen from a helicopter in low flight. The pilot may perceive two *figur-ground-relationships*: either he sees the tree as a figure and the wood as background or he sees the wood as figure and the sky as background. This may especially happen when the tree is of the same species as the trees in the front row of the wood. In this case it may be totally ignored as it is in no way special in relation to the other trees and it thus becomes part of the larger figure formed by the wood.

The main visual problem in NOE-flight is to see all possible obstacles under such conditions that they become figures against a background. It is by no means enough that they are unobstructed and "clearly visible" as an investigation-board would almost certainly write in its report.

Final remarks

Robinson, in his book on the psychology of visual illusion (16), writes: "An interesting attitude towards illusions is that which regards them as the debt which the visual system pays for other advantages in the process of seeing. The system has developed in such a way that, under normal circumstances, the maximum amount of information is gained from the visual field. The special tricks that it plays usually serve this end remarkebly well, but there are odd situations, usually ones which could not possibly have been important to primitive man, in which the tricks are turned against the system".

However, it has to be pointed out - and this is valid for all perceptional factors mentioned before - that under optimal visual conditions and when it is well known what is seen the influence of these factors on the development of perceptions is overruled by experience and disorientation is thus prevented. But it cannot be stressed enough that under deteriorating weather-conditions and in unknown surroundings when visual cues become scarce and uncertain the above mentioned factors will be the mould in which the brain casts what visual stimuli it has and then the chances are high that perceptions coming out of this mould are not always congruent with reality.

In order to understand why pilots get disoriented one has to keep in mind that all visual cues
- are processed by an active brain according to innate perceptional laws
- interfere with each other
- are influenced by previous visual experiences
- are loaded with emotions, expectations, moods and motives

The main point is: to see is not to perceive !

DISORIENTATION COUNTERMEASURES

There is practically no pilot who has not at least once in his career experienced disorientation, and when one reviews what has been said in the previous chapters, then this is not astonishing at all. Fortunately, most cases of disorientation are only mild and recovery can be made by the pilots in due time before anything disastrous happens. Nonetheless, the problem remains and has to be solved.

1. Spatial Disorientation Familiarization Devices

Much time and money has been devoted to the construction of ingenious devices which induce most of the common vestibular illusions which lead to disorientation. These devices are fine to demonstrate vestibular disorientation and trainees are quite impressed by the kind of illusions they experience. But it has to be pointed out that these apparatuses do not impart any techniques to prevent disorientation or even to become less susceptible to disorientation. It is probably possible to train pilots to be less prone to airsickness but no matter how often pilots are trained in such devices they will lose their orientation within 20 seconds or less should they ever try to fly without any visual cues - be it from outside references or from instruments. That is nice to demonstrate but no pilot would be stupid enough to insist on a demonstration before he could be convinced. Every student pilot experiences from his first flying hour onward that it is not his sense of equilibrium which helps him to keep the aircraft on a coordinated flight path. Instead he quickly learns that for that purpose he has to rely on his eyes only. In fact it seems to be questionable whether those devices which provide the trainee with no visual cues whatsoever about his real position in space serve their purpose properly. The only technique which will save a pilot who has become disoriented is that in which he disregards his sense of equilibrium completely and tries to gather as many visual cues as possible containing hints as to his real position in space. In these apparatuses, however, the trainees are requested to concentrate on their feelings of their position in space - which is the only thing a pilot should not do! It is always a doubtful pedagogical technique to teach things in order that they should not be done. In fact the only purpose of spatial-disorientation-familiarization devices seems to be to show that it is possible to evoke spatial disorientation in a test person even though being safely on terra firma.

2. General Instrument Flying Training

When spatial disorientation is such a common experience among pilots and when it is well known that "seat of the pants-flying" is under such circumstances the surest way to death, then there is no alternative to a sound training in instrument flying - for every pilot! Each and every pilot should at least be capable of flying basic manoeuvres and to be able to recover from unusual attitudes on instruments alone. There is no alternative to this! (14)

It may happen to the most cautious and prudent VFR-pilot that he encounters weather-conditions where no escape is possible and visibility drops to zero from one second to the other and if he is not able to go on instruments instantly it will take him less than 20 seconds to lose his orientation and a few minutes depending on the altitude he was at when he entered the cloud until he is dead.

No spatial disorientation familiarization training will help him in such a situation. What will help him is a

- thorough training in basic instrument flying, either under the hood or in a simulator

- belief in the instruments
- self-confidence, that he can cope with the situation and derived from this
- calmness.

The first point will help him to handle the aircraft properly and the last three points will help him to avoid spatial disorientation.

While there is no way which leads around a basic training in instrument flying for all pilots to minimize accidents due to spatial disorientation, there is still a lot that can be done to improve the visual behavior of pilots, because it is vision which is at the very roots of the problem. Instrument-flying-training is useless if the pilot misreads instruments, or looks at them in a wrong sequence or even disregards them completely, and he will be lost and prone to hit an obstacle if he doesn't look outside and doesn't know what to look for.

3. Perceptual Training

All reports of cases of disorientation have one thing in common as was said before: disorientation is triggered off by inadaquate, or erroneous, or disregarded visual cues. Those rare cases where disorientation is experienced even when the pilot felt that adaquate visual cues were available are actually cases of susceptibility to airsickness either due to physiological reasons or due to psychological factors related to the flying environment. These are not cases of disorientation in the sense in which it is used here as persons experiencing disorientation under such conditions are not fit for flying and should be treated accordingly. However, on closer inspection it would be possible to discern quite a few among these cases where the abundance of visual cues was used wrongly and thus initiated disorientation.

My own occupation with disorientation started when I was confronted with a student-pilot who had already flown nearly 100 hours and who got lost in broad sunshine while flying over a well structured hilly countryside, which was familiar to him, displaying lots of clearly visible landmarks, one being the only river in the area. His instructor pilot had to direct him to the entry-point of our airfield which was only a couple of miles away when he first lost his orientation. A discussion with the instructor pilot revealed that the student had generally a tendency to fixate visually and that this habit was probably on the bottom of all his problem in the cockpit. It should be added that the student never became airsick.

I checked the student in a simulator - like testing device (Fig. 18) and found that when put under stress his eyes actually stopped moving. As he was otherwise capable of performing quite well and especially as his training had cost already a lot I decided not to vote for elimination from flying training but to try to develop a visual training program for him. This program comprised several steps and included the major points of Huxley's book "The art of seeing" (10).

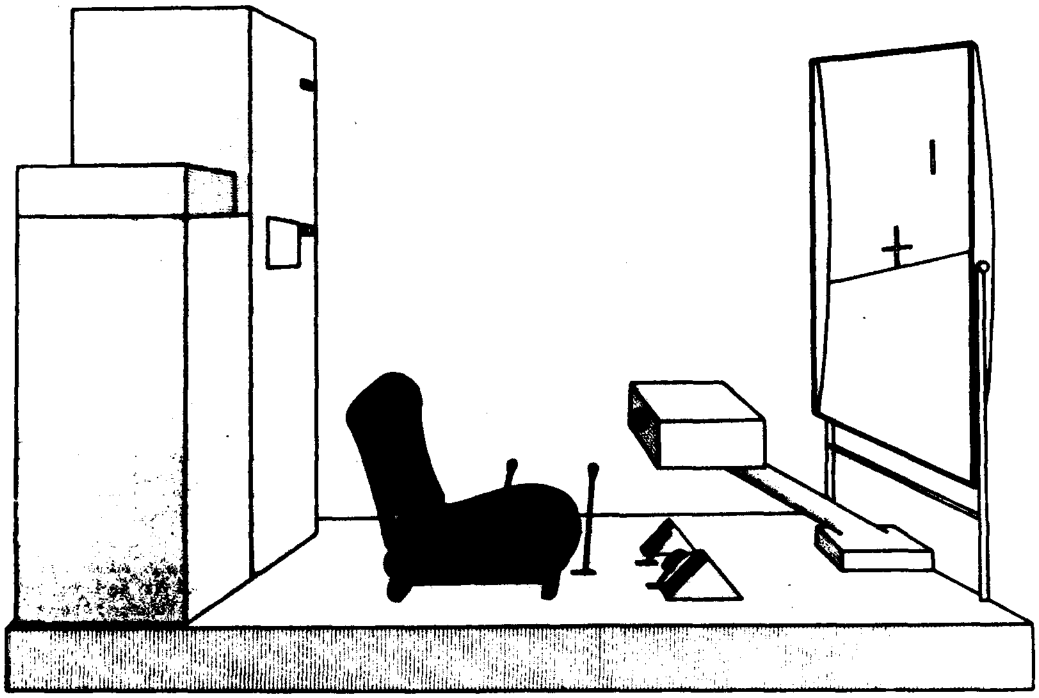


Fig. 18: Precision-Coordination-Analyzer (PCA)
This testing-device is used for pilot-selection in the German Armed Forces. It comprises a screen on which a movable horizon-bar and a direction indicator are projected and an instrument panel displaying a speed indicator and several warning lights. Speed indication and position of the horizon are interrelated. The subject keeps the horizon level and on the cross in the middle of the screen, the direction indicator in the middle above the cross and the speed indicator on the requested mark by means of a control stick, pedals and a throttle. Deviations from these normal positions are generated automatically by the apparatus and the time it takes the subject to steer each of the parameters back to normal position is recorded.

Visual Training Program

Step 1: Relaxation training

In a discussion the student and I analyzed his faulty technique of scanning his surroundings when put under stress. Before the actual training started he had to understand the following points:

- When put under stress you want to see everything at once,
  You are trying to open your eyes as wide as possible without moving them - you are staring!
- Staring results in a general tenseness!
- Tenseness and fixed eyes will result in a blurred vision - your eyes will be out of focus!
- Blurred vision demands more activity on the part of the brain
- The brain will be overloaded - which can lead to a fluctuating focus of attention and to airsickness

The first training step was therefore to train him to stay relaxed when put under stress. This was done on the testing-device shown in Fig. 18. He was given a difficult coordination task which quickly made him to become stiff at the controls while his eyes became rigid. At that point the coordination-task was immediately interrupted and muscle relaxation according to Jacobson was begun (of course, he had gotten an introduction into this relaxation

method before the actual training program had started). This was continued for several one-hour-sessions until he started to show something like a conditioned reflex: touching a stick and seeing instruments and a moving horizon in front of him meant to sit back relaxed.

Step 2: The second part of the program contained the following items (actually after three sessions it was possible to train the two steps simultaneously). He was given a briefing on the symptoms of staring:

- Blinking of the eyes is reduced
  Consequence: eyes become dry and will burn!
- Breathing is stopped
  Consequence: brain will get less oxygen!
- Brain will allow focus of attention to oscillate
  Consequence: Symptoms of mental overloading
  Fealing of nausea
- If you want to see as much as possible
  - o you have to move your eyes
  - o you have to blink frequently
  - o you have to breath regularly
  - o you have to be relaxed

The practical training program comprised breathing exercises while performing coordination exercises on the testing device. This was followed by a special exercise where he was requested to move his fixation point around thescreen in front of him, never looking into the center of the screen by fixating the four corners of the screen in succession for approximately one second each. He was impressed to find out how much his ability to coordinate the controls improved once he was no longer allowed to look directly at the horizon bar.

Step 3: The third and last step of the training program comprised mental training to familiarize him with a technique to generate in advance a mental image of what he was going to see when flying low-level-routes. Again he was given a briefing:

- What is dynamic-relaxed looking?
  - o Frequent, relaxed blinking
  - o Relaxed breathing
  - o High frequency of short looks ("lightning") and mental visualization of what was seen
  - o Analytic looking: quick scanning of the surroundings divided in small sections
  - o Figur-Ground-Visualization: visualize the object you are looking for mentally in front of a white background

Practical training comprised flying well-known low-level-routes mentally with eyes closed. For each leg (2-3 minutes) he was allowed to look in the map and then he had to describe what he would see if he were actually flying the route. He was asked intermittently to mentally read the heading indicator or other relevant flight instruments and state their probable readings.

To end the program he was given a final briefing stressing the following points:

- To look is not to see (perceive)!
- You have to know what you are looking for! (Mental image)
- If you look for something, without having a mental image of it, you will detect it in your visual s‿rroundings only by chance!
- If you don't know what you are seeing, then your brain will decide what it could be for you.
- You have to be motivated to perceive.
- If you don't want to be deceived by your perceptions you have to exercise your visual memory!
- Don't say: what I see is true
  But say instead: Can what I perceive be the reality as I know it or as I expect it to be?

Final Remarks

This visual training program, with minor alterations to suit different problems, has been given to ten student pilots up to now who were all reported by their instructor pilots for having shown symptoms of disorientation either when flying instruments or low-level-missions. Comments of the instructors and the students on the results of the program were favorable. None of the students has been eliminated from flying thus far though all of them had been on the verge of elimination when they were reported to the aviation psychologist.

All this encourages us to develop this training-program from its present experimental status into a program which could become an integral part of flight training.

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HEARING LOSS ASSOCIATED WITH HELICOPTER FLIGHT

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INTRODUCTION

Considering the importance of hearing acuity for flying fitness of aircrews, authors have repeatedly attempted to describe and compare the occurance and the influence of hearing damages caused by aircraft noise. Among other criteria this leads to an establishment of differentiated flying fitness regulations (Provisions on qualification for flying duty) and to the use of pure tone audiometry as a means of routine monitoring of noise-exposed personnel by comparison of hearing losses. In the audiometry tests conducted in the course of examinations for Qualification for Military Flying Duty at the German Air Force Institute of Aerospace Medicine marked hearing losses in the high frequencies especially in Army helicopter pilots were occasionally found. Through a comparative examination this study attempts to determine whether higher hearing losses can indeed be observed in helicopter pilots of the Army as compared to pilots of the other Services. It is further investigated whether helicopter-specific noise characteristics cause significant hearing losses in pilots, which are more pronounced in Army pilots as compared to pilots of other aircraft types.
In 1967 the German Air Force Institute of Aerospace Medicine began centralized data storage of all findings of medical examinations for qualification for flying duty including audiometric data, classified according to test frequency and hearing loss. By the end of 1977 these findings had been transferred onto punch cards after previous coding; as of 1978 they were directly fed into a modern electronic data storage system. Thus today all audiograms - left and right ears separate - taken since 1968 are available for evaluation.

METHODOLOGY

To compare hearing losses between Army helicopter pilots and pilots of other aircraft types, we first evaluated the audiograms of those pilots who were examined by the ENT Section of the German Air Force Institute of Aerospace Medicine in 1969 through 1971 during the course of Medical Examinations for Qualification for Military Flying Duty. In addition we selected a second pilot collective. This included all pilots who reported for Medical Examinations for Qualification for Military Flying Duty to Fürstenfeldbruck in 1978 through 1982.
The audiograms of these pilots formed the basis for a further comparative study, which in its result was to be compared with the findings of the first group.
The reason for such a procedure is not only the fact, that different forms of data storage also required different methods of evaluation related to the specific form of storage (e.g. audiograms of the years 1969 - 1971 were stored in a coded mode according to hearing loss categories, later on in an uncoded mode).
A comparison of the findings of this nature is also informative due to the fact of meanwhile (approximately since 1970) changed attitude towards the necessity of adequate ear protection during nose-exposed activities. Today even the older pilots routinely wear their ear protectors convinced of the necessity to maintain their hearing capacity,who formerly disapproved of ear protectors for reasons of comfort. Moreover, ear protection regulations in the services have become more rigid and compliance with as well as practicable application of these measures are constantly enforced, e.g. during firing practice or during maneuvers. In recent years, moreover, new weapon systems have been introduced in the German Federal Armed Forces which meet the requirements of hearing protection by way of construction. It is the multitude and frequency of noise-traumatic events that give cause to discuss the subject matter:

DO ARMY PILOTS CAUSED BY EXTERNAL CIRCUMSTANCES SUCH AS SPECIAL TRAINING REQUIREMENTS AND SPECIFIC AIRCRAFT NOISE SUFFER GREATER HEARING LOSSES IN COMPARISON TO THEIR COMRADE PILOTS?

ACCOMPLISHMENT AND RESULTS

During 1969 through 1971, audiograms (right and left ears separate) were performed in 1949 candidates for flying duty in the German Air Force who passed through the ENT Section during the course of Medical Examination for Qualification. In addition audiograms were performed in 1913 pilots who went through the periodic medical examination at the German Air Force Institute of Aerospace Medicine in 1971.
To assess these audiograms the findings were classified into 10 different categories and coded accordingly:

0 : Normal audiograms (not more than 20 dB HL from 250 - 6000 Hz)
1 - 3 : Conductive types of hearing losses of three different degrees
4 : Perceptive type of hearing loss above 3000 Hz
5 : Perceptive type of hearing loss above 2000 Hz
6 : Perceptive type of hearing loss above 1500 Hz
7 : Perceptive type of hearing loss poorer than 6
8 - 9 : Mixed types of hearing loss.

Candidates showing conductive and mixed types of hearing losses are disqualified in the initial medical examination of pilots; therefore their portion in the pilots is below 2% and negligible for our report. Since hearing losses of category 7 disqualify, we are only concerned with typical high tone hearing losses of the categories 4, 5 and 6.

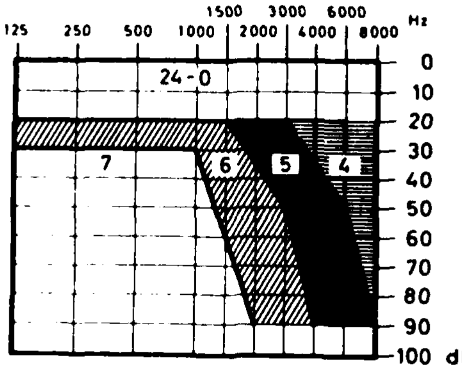


Fig. 1

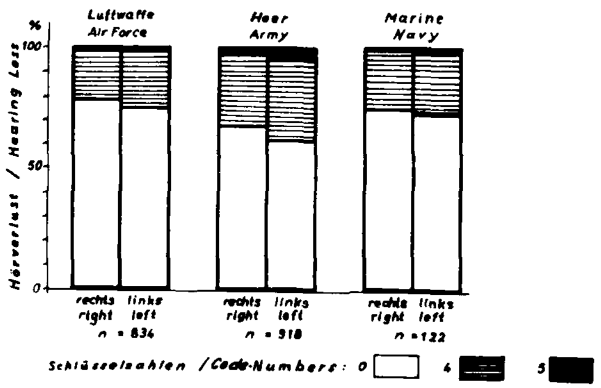
Einteilung der Hörverluste mit Schlüsselzahlen.
Classification of Hearing Losses with Code Numbers

According to the provisions on qualification in the German Armed Forces pilot candidates with slight high frequency hearing losses above 2000 Hz are acceptable. The total hearing loss in both ears for the frequencies 3, 4 and 6 KHz (Kilo-cycle per second) must not exceed 210 dB, i.e. the one-sided hearing loss of the most affected ear may amount to 70 dB in these three frequencies or in the case both ears are affected, a hearing loss of 35 dB for the corresponding frequency may still be tolerated. Contrary to this only hearing losses of up to 30 dB are tolerated in the medium frequencies from 250 - 2000 Hz. See fig.

Application of such a flexible standard is justified since we know from own experiments that high tone hearing losses within these limits will not impair the speech intelligibility of the pilots to any great extent. Even when using ear protective devices such a high tone hearing loss may still be tolerated with a view towards speech intelligibility.

Percentage distribution of hearing losses within the separate categories during the initial medical examinations reveals a slightly higher portion of hearing losses within category 5 in the Army as compared to the Air Force. There is a distinct difference in the portion of category 4 when comparing the Army versus Air Force and Navy.

Fig. 2



Prozentualer Hörverlust gemäß Schlüsselzahlen bei der Erstuntersuchung
Percentage of Hearing Loss according to Key Numbers for First Examination

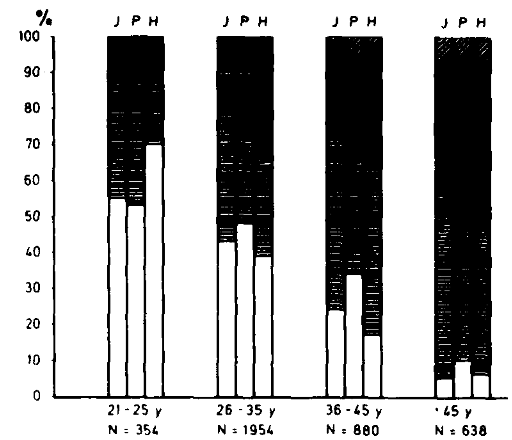
In all pilots hearing losses of the left ears are dominant.

In a further study the percentage of all hearing losses of the code numbers 4, 5 and 6 of all audiograms of pilots in the year 1971 were computed. They were classified into four groups each according to age and flying time and into three further subgroups concerning the pilots of jet-, propeller aircraft, and helicopters.

% Distribution of hearing losses versus age

J = Jet, P = piston - engine fixed wing, H = helicopter

Fig. 3

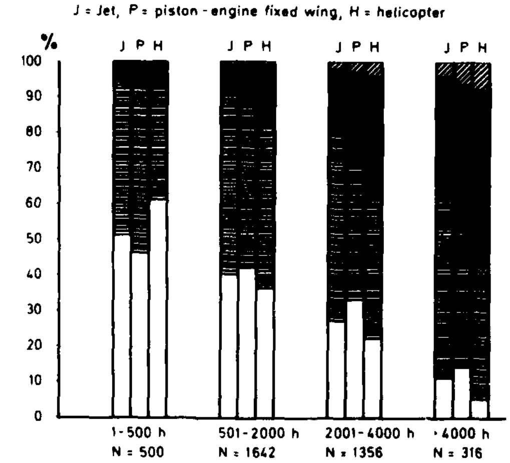


Here a constant reduction of normal-hearing pilots and an increase in number and degree of high tone hearing losses is found with increasing age and increasing flying time. The percentage of negligible hearing losses in category 4 above 3000 Hz remains rather constant. A marked increase, however, is evident in the hearing losses above 2000 Hz = category 5, particularly in helicopter pilots of the age group 36 - 45 years and in all pilots above 45 years. Hearing losses of code number 6 are not found in younger age groups, their maximum lies at 10% in pilots of the age group above 45. This is due to the fact, that these older pilots have already flown in the last war when noise levels in the aircraft cockpits were considerable higher, when ear protection through flying head gear was low and the flying time per year was clearly above the average achieved today. We assume, that the situation will become more favorable when the combatants have retired and the present age group from 36 to 45 will become the highest age group. When viewing hearing loss distribution as result of flying time, we find the same tendency as before in the age dependency.

% Distribution of hearing losses versus flying time

J = Jet, P = piston - engine fixed wing, H = helicopter

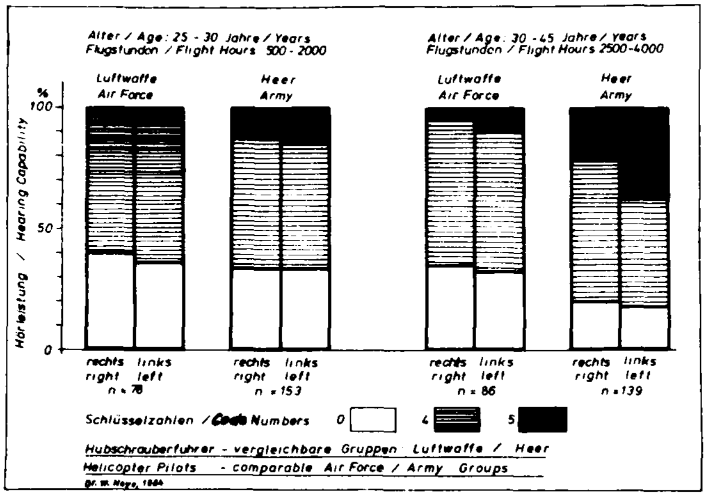
Fig. 4



Particularly the hearing losses of the code numbers 5 and 6 increase, again slightest in the jet pilots, and highest in helicopter pilots. From these facts it might be concluded that the noise caused by helicopters is more damaging to the hearing capacity than that of other types of aircraft. For this reason we compared the hearing loss distribution of 47 helicopter pilots of the Air Force with that of 148 helicopter pilots of the Army, namely in the age groups 26 to 35 years and 501 up to 2000 flying hours. Furthermore we compared 69 helicopter pilots of the Air Force with 118 corresponding pilots of the Army, age group 36 to above 45 years and 2001 up to 4000 flying hours, right and left ears separate. The following was found:

1. In pilots of the Army the percentage of hearing losses in category 5 was twice as high as in those of the Air Force:
2. In the hearing losses above 2000 Hz resp. 1500 Hz the left ears were affected twice as much than the right ears.

Fig. 5

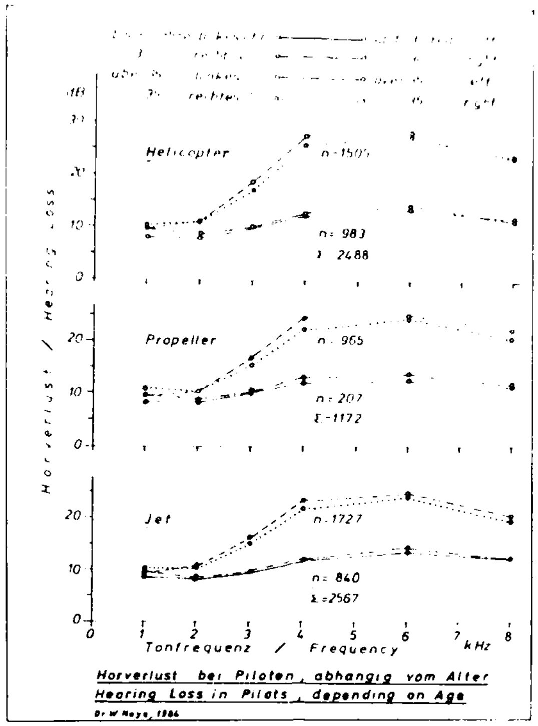


These facts cannot only be attributed to helicopter noise since on the one hand pilots of the Air Force were exposed to the same degree, on the other hand both ears would have to be affected almost to the same degree. The most plausible explanation is the fact, that Army pilots, before entering flying service and during their flying career, have considerable more firing practice because of specific training requirements than pilots of other services, in the past very often without adequate ear protection. The difference in the ears affected by hearing losses can probably be explained by the type of weapons used. Thus e.g. the muzzle report of a rifle fired by a right-hander will hit the left ear at approximately 160 dB (machine gun at 155 dB per round), whereas the right ear lies in the sound shadow of the head. The recoilless antitank grenade launcher and similar weapons, however, will predominantly affect the right ear of the rifle man with 165 up to 180 dB depending upon ammunition. Since these weapons are also applied in the Army less frequently this offers a possibility to explain the side differences in traumatic hearing losses caused by firing bangs.

In recent years the demand for adequate ear protection especially for pilots has met with more success also in the Army. An ordinance has been decreed for the Army to the effect that pilots will no longer be charged with supervisory functions during practice firing and that they will no longer be required to fire the recoilless antitank grenade launcher. In comparison to earlier years the pilots have gained a better understanding that it is in the interest of their own qualification for military flying duty to pay attention to adequate noise defenders and to wear ear protectors not only - as ordered - during firing practice but also as a protective measure during other nose stress. This makes it interesting to perform another examination to assess the extent of traumatic hearing losses under improved conditions of protection against noise and after the introduction of new and less noise-intensive types of aircraft. On the other side, after the adoption of more sophisticated weapons and weapon systems, e.g. the greater speed of the projectiles and the increased rate of firing or permanently noise-generating auxiliary power units, there are hints pointing to greater hearing losses resulting therefrom.

For the recent examination we selected the period between 1978 - 1982. In this period and in addition to all other pilots all helicopter pilots of the Army were examined once or several times at the German Air Force Institute of Aerospace Medicine. Pilots above 40 years are examined once every year, younger pilots, however, report for medical examination to the German Air Force Institute only once every three years. Their audiograms, now uncoded, were fed into modern electronic data storage systems. A total fo 15 388 audiograms were available for evaluation. These examinations were always performed by the same lady audiometrist and with the same PHILIPS clinical pure tone audiometer in a well noise-shieldd booth, type Amplifon. Evaluation of the examination revealed:

Fig. 6

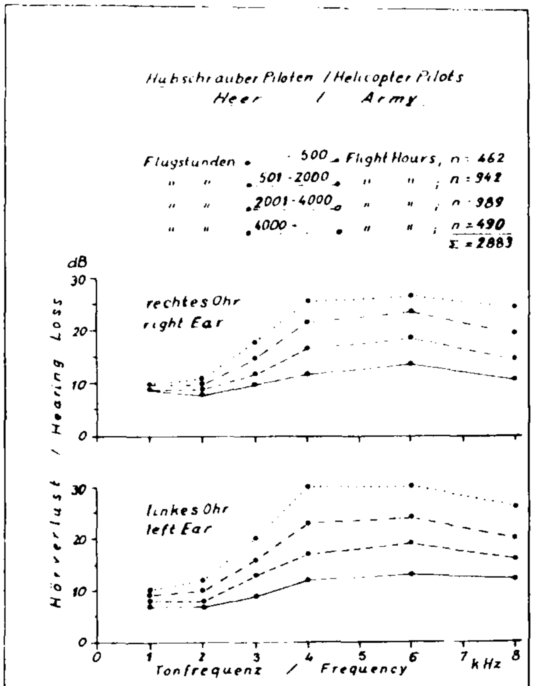


1. The hearing loss presentation, related to age, of the helicopter pilots of the Army clearly shows an increase of hearing losses in the frequencies between 3 - 8 KHz. This increase is already marked in the age group up to 30 years, but is considerably more pronounced with increasing age as can be seen from the tracing for the pilots above 35 years. Right and left ears are nearly congruent and indicate a symmetric hearing loss in the test frequencies. In the age group of pilots up to 30 years there are no essential differences when comparing them with prop- and jet pilots. In the frequencies between 3 and 8 KHz all pilot groups for the age group up to 30 years show slightly higher hearing losses. They are the result of the qualification standards which permit high tone hearing losses in the aforementioned limits during initial medical examination. This picture changes, however, when viewing the high tone hearing losses in older pilots in comparison. Here smaller hearing losses are noticeable in prop- and jet pilots in all frequencies starting with 3 KHz.
   In this comparison we have also evaluated right and left ears separately. In doing so the pilots of the three types of aircraft considered here in the age group up to 30 years revealed no significant differences. Also in the age group above 35 years differing hearing losses of the right ear in comparison with the left one can not be proven for sure even though the differences are more marked than in younger pilots.

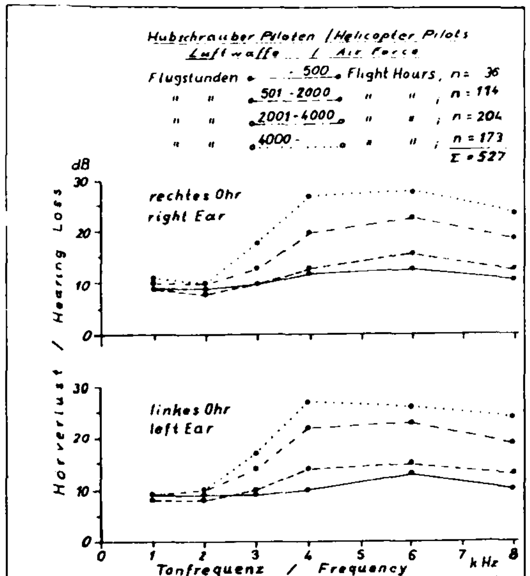
2. The following diagrams show hearing loss dependencies upon flying time as found by us. Here we compared Army helicopter pilots with Air Force helicopter pilots and also with those of the Navy as well as jet- and prop-pilots. All flying time groups with the exception of the group with up to 500 flying hours show greater hearing losses as of 3000 Hz as far as Army pilots are concerned. The increase is more marked with higher flying time. The finding in the column of 2000 - 4000 flying hours is remarkable.

   Here helicopter pilots of the Army, Air Force and Navy as well as jet- and prop-pilots show a nearly similar progress of the hearing loss tracings. Hence hearing losses during this flying time are non-specific as to aircraft type. The figures computed for the Navy pilots are statistically irrelevant in this context due to an insufficient number of cases.

   The above mentioned observations are in line with the results of the separately examined right ears. However, right ear hearing losses are slightly less than in left ears. (Side differences = 6 dB).



Hörverlust bei Piloten, abhängig von Flugstunden
Hearing Loss in Pilots, depending on Flight Hours
Dr. W. Neye, 1984



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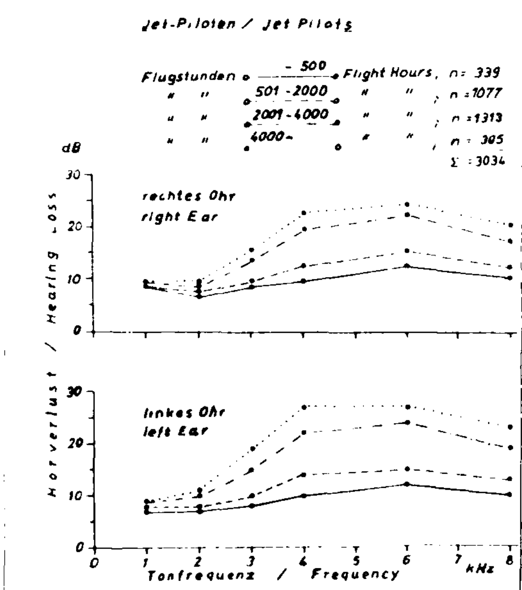

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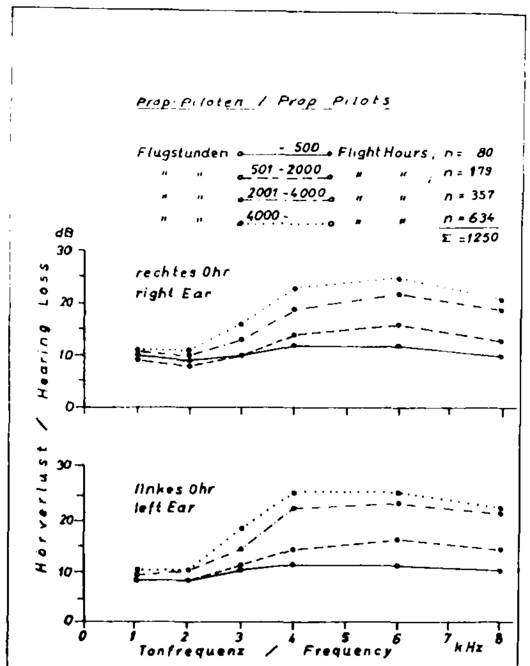


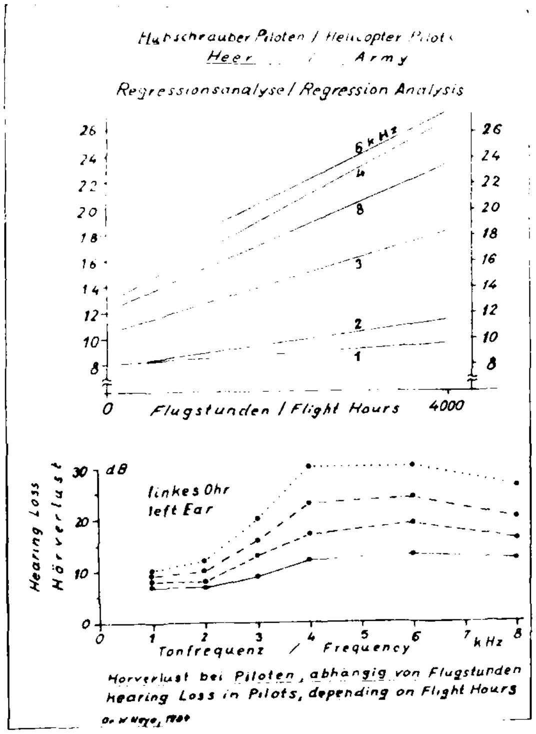
Hörverlust bei Piloten, abhängig von Flugstunden
Hearing Loss in Pilots, depending on Flight Hours
Dr. W. Neye, 1984

In order to statistically evaluate the present results and in an effort to furnish unequivocal evidence of a stronger, aircraft-noise-induced hearing loss increase in Army helicopter pilots versus other pilots, a correlation and also a regression analysis was performed for the hearing losses in the frequencies from 1 to 8 KHz and the differences of the regression coefficients were calculated.

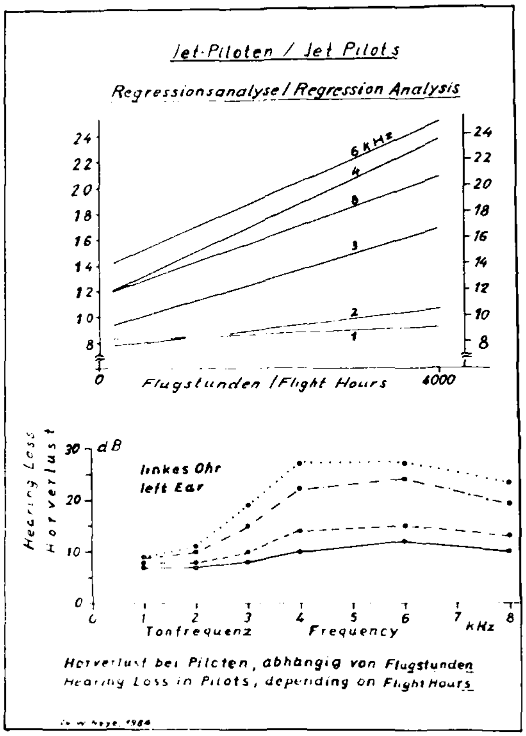
All examinations of th. ENT-Section of the German Air Force Institute of Aerospace Medicine in the years frp, 1978 to 1982 were included and hearing losses in the frequencies 1,2,3,4,6 and 8 KHz were examined. For all pilot groups in all frequencies with the exception of the hearing losses at 1 KHz in the group of Air Force helicopter pilots this revealed a significant correlation of hearing losses with flying time.

Correlation in all four pilot groups (Jet (n=3034), Prop (n=1250), Helicopter (n=2883), Helicopter Air Force (n=527) is closest at 4 KHz. Thus, if hearing losses occurred in dependence of the number of flying hours they were first to be expected at 4 KHz. For a quantitative comparison of the probability of hearing loss dependence upon aircraft noise in the pilot groups, coefficients were calculated in the regression analysis which reflect the increase of the regression line and its starting value. Thereby the ascent of the line indicates the hearing loss increase per flying hours and hence is the measure of the hearing loss as a result of the correlating stress of flying hours. The steeper the ascent, the greater the probability of hearing loss dependence upon specific aircraft noise stress.

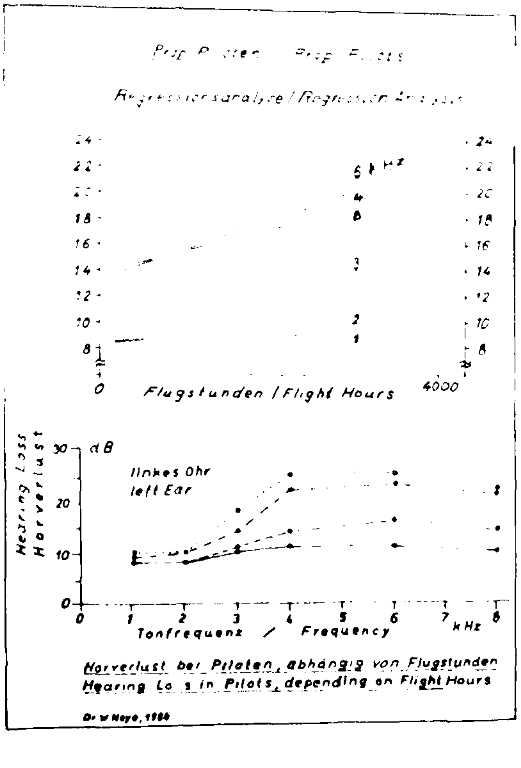
In general our data revealed greater ascent in the frequencies from 3 to 8 KHz; at 1 and 2 KHz they are not marked (see Fig.). In consequence we shall only deal with the frequencies from 3 to 8 KHz. In these frequencies the group of Army helicopter pilots show the absolutely highest increases, followed by the groups of Air Force Jet- and Helicopter pilots. The ascent in the group of prop pilots is distinctly lower, but this group shows the highest values of initial hearing losses.



Hörverlust bei Piloten, abhängig von Flugstunden
Hearing Loss in Pilots, depending on Flight Hours



Hörverlust bei Piloten, abhängig von Flugstunden
Hearing Loss in Pilots, depending on Flight Hours



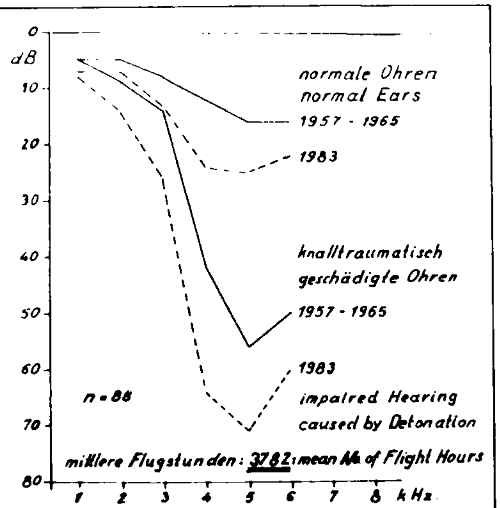
Hörverlust bei Piloten, abhängig von Flugstunden
Hearing Loss in Pilots, depending on Flight Hours

If comparing the separate pilot groups with one another in order to find out whether the initially mentioned problem can be substantiated, namely that helicopter pilots of the Army will show stronger and significant hearing losses due to helicopter-specific noise characteristics with increasing flying hours, the following is found:

ENT-Evaluation: Hearing Losses
Values of Regression Line for Graphic Presentation

	Jet		Prop		Helicopt.(Air Force)		Helicopt.(Army)	
	0 hrs	4000 hrs	0 hrs	4000 hrs	0 hrs	4000 hrs	0 hrs	4000 hrs
1 kHz	8.28	9.08	8.37	9.57	8.93	9.73	8.07	9.67
2 kHz	7.68	10.48	8.55	10.15	8.82	10.42	7.92	11.52
3 kHz	9.04	16.64	9.31	15.71	9.50	15.90	10.34	18.34
4 kHz	11.67	23.67	13.38	22.58	11.88	24.28	12.75	26.75
6 kHz	13.75	24.95	15.81	23.01	14.29	24.29	14.68	27.48
8 kHz	11.92	20.72	13.81	20.61	11.06	21.46	12.20	23.40

The increase of hearing losses in Army helicopter pilots versus jet pilots is significant at 4 and 8 KHz, in comparison with prop pilots it is highly significant in all 4 frequencies, in comparison with helicopter pilots of the Air Force, however, it is only slightly significant at 6 KHz. This leads us to the conclusion that in helicopter pilots of the Army the type-specific aircraft noise is responsible for a statistically secured marked hearing loss increase with increasing number of flying hours in the high frequencies. This dependence of hearing losses upon specific aircraft noise is smaller in jet- and prop-pilots, but nevertheless, statistically secured also in those cases.
For Army pilots and Air Force helicopter pilots the regression lines progress nearly parallel, therefore the increase of hearing losses per flying hours is nearly the same in both groups. This means that both pilot groups are almost identically damaged by aircraft noise. Only at 6 KHz there is a stronger aircraft noise-induced hearing loss difference between Army pilots and helicopter pilots of the Air Force.
An explanation for this finding may be that helicopter pilots of the Air Force fly only the BELL-UH-1, whereas Army pilots constantly operate also other types of helicopters. This may also serve as an explanation for the missing significance when comparing helicopter pilots of the Air Force with jet pilots.
A further corresponding inter-pilot group comparison reveals that of all pilot groups the prop pilots have to expect the slightest aircraft noise induced hearing loss.
In order to follow the development of high tone hearing losses incurred prior to flying training under the influence of the specific helicopter noise characteristics, we, in a long-term study, examined 88 helicopter pilots of the Army, who had suffered one-sided damages from noise or shooting sounds between 1957 - 1965. In 1983 after an average of 22 years = 4000 flying hours a comparison with the initial audiogram of these pilots showed the following increase in mean hearing losses:



Verlauf des Hörverlustes einseitig knalltraumatisch geschädigter Ohren

History of Hearing Loss in single-sided impaired Ears caused by Detonation

1	2	3	4	6	8 KHz	Increase of hearing losses in shooting-sound damaged ears after app. 22 years.
3	5	12	22	15	10 dB	

In comparison the non-damaged ears showed an even slighter hearing loss increase with a maximum of 12 dB / 4 KHz at an average.

1	2	3	4	6	8 KHz	Increase of hearing losses in shooting-sound damaged ears after app. 22 years.
2	2	5	12	9	5 dB	

APPRAISAL AND DISCUSSION

Statistical evaluation of the pure tone audiograms of helicopter pilots of the Federal Armed Forces in the years between 1969 - 1971 and 1978 - 1982 revealed normal hearing capacity in more than 65 % of the pilots who were at the start of their flying career. The remaining portion of this group showed hearing losses above 4 KHz which were found approximately 10 % more often in comparison with the pilots of other services. With increasing age and concurrently increasing number of flying hours the number of hearing losses increases in percent also in the medium frequency range. Thus our reporting period showed a constant decrease of pilots with normal hearing acuity with increasing age. In older pilots and with higher flying hours the hearing losses of category 5 meaning hearing losses above 2000 Hz increase markedly. Again Army pilots in the age group between 36 - 45 and above with 2000 flying hours and more were predominantly affected. The hearing loss increase calculated here is characterized by a maximum at 4000 Hz and this frequency-related hearing loss maximum is likewise true for pilots of all aircraft types. It is this statement as well as all findings reported before that are substantiated by FRÖHLICH 1981 1) and DIEROFF 2), who in noise-induced hearing losses has noticed a marked dependence from the years worked under the influence of noise and who after a phase of adaptation and good compensation reports a marked increase of hearing losses after approximately 10 years. JANKOWSKI 3) and LANDGRAF 4) also found a critical period of noise tolerance in pilots. To be sure, mention is only made of the age dependency of hearing losses in relation to increasing flying hour stress. As in our case no collective of older pilots with little flying hours resp. no collective of younger pilots with exeptionally many flying hours were available for the examinations mentioned. In our examinations the mean hearing losses in all pilot groups are between 20 - 30 dB starting with 4 KHz, whereby Army helicopter pilots with approximately 35 dB between 4 - 6 KHz lie highest. This finding is supported by J. KRESSING 5) (1975), who found a dependence of hearing losses from flying hours in 20 - 40 year old pilots starting with 4000 Hz and who lists the mean hearing loss as being approximately 25 dB.
Only above 6000 flying hours does the same author report slight side-differences in hearing losses between left and right ears (-app. 5 dB), but aside from that did not notice any significant relationship in side-differences as related to aircraft noise-induced hearing loss.
Our study between 1969 - 1971 Army helicopter pilots showed twice as many hearing losses above 2000 Hz in the left ears in comparison to the right ears. This finding is not repeated in the examination which followed in the years 1978 - 1982. Only side differences averaging 5 dB were found. This leads to the conclusion that hearing damages predominantly caused by shooting sounds could meanwhile be considerably reduced by adequate noise diminishing measures and further ear protection regulations.

CONCLUDING REMARKS

The present comparative examination revealed indeed, that greater hearing losses can be observed in helicopter pilots of the Army versus pilots of the other services. With a high degree of probability they are the result of the special training requirements of Army pilots and the aircraft-type-specific noise intensity associated with helicopter flying.
Nevertheless, these hearing losses in Army pilots with few exceptions lie clearly within the qualification limits promulgated for military flying duty in the German Federal Armed Forces. Provided applicable ear protection regulations are observed even long-term aircraft noise exposure will not cause above average hearing losses in helicopter pilots which might considerably impair the earning capacity or quality of life in older age. All helicopters employed by the German Federal Armed Forces are flown by pilots wearing flying helmets. Noise attenuation characteristics of these helmets protect effectively against the damaging noise intensities. Critical noise levels may, however, be experienced during external work on aircraft or during flight line operation near the runway. In those cases further measures have to be initiated, which bring about a reduction of noise caused by aircraft in flying operation as well as measures to improve ear protectors for pilots and nose-exposed maintenance personnel. To illustrate, the use of a soft plastic earplug standardized within the German Federal Armed Forces to be worn under the steel helmet or flying helmet is urgently demanded for reasons of hearing loss prevention.

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THERMAL CONTROL PROBLEMS IN MILITARY HELICOPTERS

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SUMMARY

The origins of thermal problems in military helicopters are discussed and compared with those of fixed wing aircraft. Some typical helicopter sortie temperature profiles are presented for hot and cold environments. The requirements for protection from chemical warfare agents are described in relation to helicopter operations and the additional thermal problems arising from chemical protective assemblies and drills are described. Potential adverse effects on aircrew performance and fatigue are considered. Thermal hazards in post-crash survival situations are also considered particularly those related to ditching in cold water.

Various approaches to the relief of thermal stress in helicopter aircrew are considered. The limitations of engine powered environmental control systems and the potential advantages of personal conditioning systems are described. The advantages of liquid-conditioned systems are compared with air systems. Cold environment protection is described in terms of insulation and water exclusion and the role of electrically heated garments is described.

SOURCES OF THERMAL PROBLEMS

Any discussion of the thermal problems associated with flying, whether in fixed wing aircraft or helicopters, should start with a consideration of the sources of heat. In high performance aircraft these are:-

(i) Aerodynamic heating

(ii) Avionic equipment

(iii) Solar radiation

(iv) The pilot's metabolic heat production

(v) Environmental heat

In fixed wing high performance aircraft aerodynamic heating during high-speed low level flight is a major source of heat in the cockpit contributing as much as 9 kilowatts or 70% of a total of 12.7 kilowatts in a typical case. Environmental heat (or cold) is relatively unimportant except during the preflight period.

Helicopters differ from fixed-wing aircraft in that aerodynamic heating is of negligible importance. Solar radiation, however, can be a major problem and because helicopter pilots tend to be heavily involved in ground activities between short sorties, the pilot's work-rate can also be an important contributor to thermal stress. Heat derived from avionic equipment is usually insignificant in battlefield or support helicopters but can be important in helicopters with extensive avionic fits such as the anti-submarine Sea King.

Because of the relatively high proportion of ground activity of helicopter crews the ambient environmental conditions assume greater significance than for fixed-wing aircrew both under hot and cold conditions. This is particularly the case in the chemical defence (DC) environment when crews are required to wear additional layers of clothing together with impermeable socks and gloves and also respirators. These items place limitations on the normal avenues of heat loss by convection and sweat evaporation and circumstances that may be acceptable for normal flying clothing become unacceptable with chemical defence assemblies. It has been widely found that the greater the physical work load of the crew the greater the adverse effects of NBC protection and this is very much the case with helicopter crews.

THERMAL CONDITIONS IN HELICOPTER COCKPITS

Several published studies give details of the cockpit environmental conditions in military helicopters (see references 2, 14, 16, 19 for detailed temperature profiles). From these studies it is clear that cockpit dry bulb temperatures during flight are frequently 5-6°C above ground level ambient with black globe temperature some 6-7°C above dry bulb. Thus in the European theatre with mean nonthly maximum temperatures, for example, of 30.8°C for July in Hanover, cockpit dry bulb temperatures of 37°C with black globe temperatures of 43-44°C can be expected.

During periods on the ground before flight or between sorties, if the aircraft is in full solar radiation, it is not uncommon to find dry bulb temperatues in the range 40-45°C and globe temperatures 50-55°C.

Data for helicopter cockpits under cold conditions have been collected during Exercise Clockwork at Bardufoss in North Norway (reference 16). In Wessex 5 aircraft flown in ambient conditions of -10°C to -15°C cabin temperatures could be maintained at +10°C without difficulty on long stable sorties in which there was no requirement for open windows. Even with open windows, cabin temperatures could be maintained around +5°C which is sufficient for aircrew dressed for arctic conditions with substantial insulation including mukluks. It is rare to find serious in-flight cold problems in modern aircraft because of the availability of very hot tapped engine air for heating. Occasionally, however, limits have to be placed on the use of tapped engine air because of the need to maintain engine performance when carrying maximum loads.

PROTECTION AGAINST CHEMICAL AGENTS

It is beyond the scope of this paper to describe in detail the chemical threat in the European theatre or indeed to detail specific methods for providing protection. However, a general description of chemical protection for helicopter crews will be given together with details of the thermal side-effects of this equipment.

The proposed method of operation for UK helicopter crews is based on effective personal protection which is donned and doffed in a specially designed 'Porton" liner. The latter provides a chemical free environment for rest and recuperation in the field.

In the case of UK Army helicopters the aircrew equipment assemblies so far trialled (Exercise Rubber Neck I, reference 11) consist of:

a. Aircrew Respirator No 5.

b. Tactical Ventilator. A fan unit that blows filtered air to the respirator.

c. Aircrew Helmet Mk 3.

d. Aircrew Gloves NBC Mk 1.

e. Aircrew Cape Leather Gloves.

f. NBC Suit No 1 Mk 3.

g. Flying Boots 1965 pattern.

h. Aircrew NBC overboots.

i. Overboots No 1 Mk 2.

j. Webbing belt and shoulder straps modified to support the respirator manifold.

k. Intercommunication unit.

The use of the ground troops S6 respirator on the ground is made possible by suitable respirator exchange drills. The AR5's are all fitted with a drinking facility; this allows prolonged wear without the risk of dehydration. The use of the S6 on the ground allows the aircrew to undertake the normal military ground duties required of them.

UK experience of helicopter trial operations in the above assemblies led to the following conclusions:

As a result of the hard work of the scientific staff and cheerful cooperation of the trial subjects, the exercise was successfully completed and a significant number of lessons learnt by all. The major findings were that:

a. Aircrew need to wear the NBC assembly on every sortie.

b. The assembly trialled allows the flying task to be undertaken for a prolonged period.

c. A minimum of 4 continuous days of intensive training in the use of the assembly is essential to gain equipment acceptability.

d. A minimum of 6 continuous days of use of the assembly is essential to regain flying task efficiency.

e. A further trial is necessary to accurately identify modifications to procedures and limitations to tasks.

As a result of trial experience some modifications are now proposed to the above assembly of which the most important is to use the UK NBC undercoverall, currently in service with the RAF, with a Mk 2A Aircrew Combat Suit over. The options to use the ground troops NBC suit and respirator for ground activities is to be retained.

THERMAL EFFECTS OF CHEMICAL DEFENCE ASSEMBLIES

In assessing the thermal cost of providing chemical protection for aircrew it is important to appreciate that one is not concerned solely with the effects of wearing extra layers of clothing. The practical provision of such protection involves aircrew in a number of complications in terms of dressing procedures, and arising from confinement to specialized buildings and facilities which are important in achieving overall protection. There are also a number of limitations and changes to normal aircraft operating procedures which combine to increase thermal stress. Finally, there is a group of problems which arise through the inability to remove sweat from the face and hands. This section starts, therefore, with a brief review of the origin of thermal problems associated with chemical protection.

DIRECT THERMAL EFFECTS

a) Clothing

Most current proposals include two extra layers of clothing over virtually the whole body surface, the charcoal impregnated undercoverall and long sleeved and legged underwear. Both are essential for protection but they increase clothing insulation, thus limiting the convective transfer of heat from the skin to the environment. Although neither layer is impermeable to water vapour they nevertheless place some restriction on the evaporation of sweat which in many practical circumstances is the pilots' main avenue of heat loss. It has been suggested that the thermal cost of these additional clothing layers seems higher than would be expected from the additional insulation and limitations to water vapour transmission. This is probably because of the tight closure of wrist, ankle and neck apertures in NBC assemblies. In normal clothing, assemblies, hot and humid air from the microenvironment beneath the clothing is constantly exchanged through these apertures with ambient air by the bellows or pumping action of normal movements. Prevention of this action increases both the temperature and humidity of the microenvironment.

In addition to the extra clothing, the head, hands and feet are covered for part or all of the time by impermeable layers; the head is enclosed by the respirator. Although the UK respirator provides an airflow over the face, which facilitates the evaporation of sweat, a large area of the scalp and neck remains unventilated. The feet are enclosed in impermeable overboots for part of the pre-flight period and the hands and wrists are covered by the NBC gloves for the whole sortie. Thus sweat evaporation from these areas is restricted or, in the case of the hands, prevented.

b) Procedures

The dressing procedures involve aircrew in increased physical effort and longer dressing times than normal. They are also confined to the protected facilities which will probably be more crowded than is usual and in which thermal condidtions will be more stressful than normal if adequate air-conditioning is not provided. Facilities for rest, recuperation, eating and drinking are likely to fall well short of those available in non-protected facilities.

INDIRECT THERMAL EFFECTS

A number of indirect thermal effects arise from enclosure of the head and hands in the respirator and NBC gloves respectively. Sweating is no new experience to the pilot but the respirator prevents him wiping sweat from his face in the usual way. The respirator ventilation system goes some way to alleviate this problem but experience to date has produced complaints of facial irritation from sweat, occasionally blepharospasm and even chemical conjunctivitis have arisen from excessive sweat running into the eyes.

The risk of misting of the respirator vizor was appreciated from the earliest stages of development. With the UK AR5 respirator this seems to be controlled by the purging air flow. In laboratory studies more serious disturbance of vision has been caused by actual sweat running down the inside of the vizor.

Enclosure of the hands in impermeable gloves not only limits heat loss from the hands but also leads to maceration of the skin with swelling of the keratinized superficial layers. There have been instances of this swelling being sufficient to limit tight closure of the hand with reduction in the power of grip and some difficulty in operating stick mounted controls.

REVIEW OF LABORATORY STUDIES

As yet there have been no systematic studies of mean thermal stress in helicopter aircrew wearing full NBC protection under realistic European theatre conditions. Exercise Rubber Neck I (reference 11) was operationally realistic but took place in March when ambient temperature was 8.7°C and thermal problems were neither expected nor seen. We must for the present rely on the results of laboratory simulations.

In this brief review of laboratory studies attention will be confined to responses in terms of deep body temperature generally measured in the auditory canal, (T_{ac}), and sweat losses. Sweat loss remains the best overall indicator of thermal strain and in the types of study involved skin temperature and heart rate changes closely follow those of deep body temperature. To avoid repetition climatic conditions will be given as Globe temperature/Dry bulb temperature/Wet bulb temperature (^oC) and details of sortie simulations will be abbreviated as crewroom (C)/duration (min), walking (W)/duration (min) and flight (F)/duration (min).

Cameron (1971)(10) exposed 9 subjects to sortie simulations in a warm (35/30/27^oC) and a hot (45/40/29^oC) climate. The simulation consisted of C/60 min, W/2.5 min, F/90 min and comparisons were made between a control clothing assembly (Helicopter Summer (AEA) and a CD AEA (CD undercoverall, CD gloves, over-helmet respirator ventilated at 100 L/min). Final T_{ac} in the warm climate was 37.41^oC (Control) and 37.52^oC (CD) and in the hot climate 37.76^oC (Control) and 38.21^oC (CD). Overall mean sweat losses were 462 g (Control) and 677 g (CD) in the warm climate, and 941 g (Control) and 1246 g (CD) in the hot climate.

Cameron concluded that the warm climate was uncomfortable but acceptable for CD operations and that in climates with 25 mm Hg WVP and globe temperatures 5^oC above dry bulb temperature, 30^oC should be regarded as the practical upper limit for air temperature. He also concluded that the hot climate was unacceptable for CD operations and would limit single sortie missions to a maximum duration of 1 hour.

Gibson et al (1978) (13) exposed 8 subjects to simulated Support Helicopter sorties under two sets of environmental conditions; 38/31/25^oC representing mean monthly maximum conditions for Germany in July, and 35/28/22^oC representing average summer conditions in Germany in July or mean monthly maximum conditions for UK in July. The simulation was designed to represent a 4 hour period in the day of an operational support helicopter pilot and included alternate 15 min periods of work and rest to simulate the varied activities of such a pilot. Work rates representing flight were at 30 W and those representing ground activities were at 76 W. (Readers are referred to Gibson et al (1978) for the rationale behind these work rates). Comparisons were made between a control AEA (Helicopter summer AEA) and a CD AEA (CD Undercoverall, CD gloves and socks, UK Aircrew Respirator NBC No 5 - an under-helmet respirator - ventilated at 50 L/min through vizor compartment).

Many subjects were unable to complete the simulation in the CD AEA and were retired before the end; comparisons have therefore been made for the data at 125 minutes - approximately half way through the experiment. This time corresponds to the end of the first sortie. T_{ac} was 37.68^oC for the control AEA and 38.05^oC for the CD AEA in the less warm 35/28/22^oC environment and 37.73^oC for the control AEA and 38.38^oC for the CD AEA in the hotter 38/31/25^oC environment. Overall sweat losses (computed from percent body weight loss given in the reference) were 508 g/hr for the control AEA and 623 g/hr for the CD AEA in the 38/31/25^oC environment, 423 g/hr for the control AEA and 554 g/hr for the CD AEA in the 32/28/22^oC environment.

Gibson et al concluded that the thermal strain observed in the hotter 38/31/25^oC environment was unacceptable and would involve limitations to physical work capacity and decrement in skilled performance. Dehydration could also be a problem if drinking facilities were not readily available. The thermal strain observed in the less hot 35/28/22^oC environment was deemed highly undesirable and also likely (18) to involve limitations of physical work capacity and skilled performance.

Thornton et al (1983) exposed 6 subjects to simulated helicopter sorties in environmental conditions of 35/35/19^oC (WBGT 23.8^oC). Subjects undertook 2 simulations, one representing a pilot's average work rate of 200 W and the other representing a creman's average work rate of 330 W. Each simulation lasted 2 hr and was undertaken once in 'control' summer clothing and once in full UK NBC protection.

For the 'pilot' simulations (200 W) final body temperatures were 36.83^oC for the controls and 37.12^oC for NBC clothing. 'Pilot' sweat losses were 340 g/hr for the controls and 525 g/hr for the NBC clothing. 'Crewman' simulations (330 W) led to final body temperatures of 37.02^oC for the controls and 37.58^oC for the NBC clothing. 'Crewman' sweat losses were 448 g/hr for the controls and 632 g/hr for the NBC clothing.

Thornton et al concluded as follows:

1. The thermal strain on helicopter crewmen operating in CD clothing in RAF Germany at summer mean monthly maximum temperatures is unacceptable. Core temperature will rise to levels at which work capacity is limited, and at which decrements in performance are expected.

2. Some degree of dehydration seems inevitable despite the availability of the drinking facility, to a level which will also limit work capacity.

3. Personal conditioning is required for helicopter crewmen under NBC conditions.

SUMMARY OF LABORATORY STUDIES

The above review covers comparisons between control and CD clothing assemblies under a range of conditions. The experiments all differed slightly in terms of subjects and simulation details, including work rates, exposure durations and detailed clothing items. Nevertheless it is useful to attempt to

combine the results to give a general overview. For this purpose the environmental data have been converted into Wet Bulb Globe Temperature indices (WBGT) for the "in flight" simulations, sweat losses have been converted to g/hr for the "in flight" period and T_{ac} has been expressed as final T_{ac} at the end of the "in flight" period. A summary of those data is given in Table 1.

SOURCE	WBGT	FINAL T_{ac} °C		SWEAT LOSS g/hr			
	°C	Control	CD	Control	CD	CD-Control	% Increase
CAMERON 1971	28.9	37.41	37.52	308	451	143	46.4
CAMERON 1971	33.3	37.76	38.21	627	831	204	32.5
GIBSON 1978	28.2	37.73	38.38	508	623	115	22.6
GIBSON 1978	25.2	37.68	38.05	423	554	131	31.0
THORNTON 1983 (Pilots 200 W)	23.8	36.83	37.12	340	525	85	25.0
THORNTON 1983 (Crewmen 330 W)	23.8	37.02	37.58	480	810	330	68.8
MEANS		37.41	37.81	448	632	184	41.1

TABLE 1. SUMMARY OF DATA FROM HELICOPTER SIMULATIONS

Thus laboratory studies suggest an overall increase of 0.4°C in final body temperature and a 41% increase in sweat loss when NBC clothing is worn on simulated helicopter sorties.

ALLEVIATION OF THERMAL PROBLEMS

In the development of helicopters engine power has always been at a premium and all increases in engine performance are rapidly exploited in terms of weapon or troop carrying capacity or range and duration. This places practical limits on the use of engine-powered environmental control systems because engine bleed air for cabin conditioning always involves losses of engine performance. It is for this reason that very few military helicopters have effective cabin cooling systems and when thermal stresses reach unacceptable levels, as they will do increasingly as the chemical defence programme develops, then we will find ourselves looking towards personal conditioning systems for a solution.

Even if it was possible to make radical improvements in engine-powered environmental control systems, this would be an inefficient method to adopt when the major cause of thermal stress is the additional clothing layers worn by the pilot for chemical defence. It is far more efficient to provide the cooling beneath his clothing by using an air ventilated or water-conditioned suit.

PERSONAL CONDITIONING SYSTEMS

i) Air systems

Personal conditioning systems based on air ventilated suits were the first to find practical application in aircraft amd were used for many years in the Royal Air Force. Conditioned air is delivered over the pilot's skin surface through a system of pipework attached to a cotton or nylon base garment - an air ventilated suit (AVS). The major problem with air systems lies in the difficulty of producing appropriate air supplies which are derived from tapped engine air and are therefore only available when engines are running and also have implications on engine performance. For an air system to be used in conjunction with chemical defence clothing assemblies it would have to include a system of chemical filters which would not only downgrade system performance but would also involve quite serious logistic problems in supplying and renewing the filters. For these reasons no air based system has ever been used in a military helicopter.

ii) Water systems

Because of the very great difference in specific heat between water and air, water has much greater heat transfer capacity at smaller cost in terms of the pumping power needed to circulate it round a suit. This fundamental advantage led to the development of water-cooled suits in the UK back in the early 1960s and this system was rapidly adopted by the USA in the Apollo space programme. The advantages of water-cooled systems were clearly demonstrated by Allan et al (1971) (3) and Figure 1 illustrates the comparative advantages in terms of deep body temperature control.

In the CW environment water-cooling has a further important advantage. Being a closed-circuit system there is no risk of introducing contamination beneath the outer protective clothing and the system requires no chemical filters.

Early developments of water-cooled suits were based on whole-body coverage (see Figure 2) but

it has been subsequently shown (Ref 8, 9) that limited coverage suits, for example liquid-cooled vests (Figure 3) can provide adequate cooling for most purposes. Head-cooling is also a possibility with water-cooled systems (7) but head-cooling caps or cowls present difficult integration problems with the other items of equipment worn on the head.

Two types of liquid cooled vest are currently available (Figure 3). The UK vest is based on a network of small pvc pipes attached to a stretch-cotton vest. An alternative type of construction has been developed in the USA and consists of two layers of coated fabric which are welded together so as to produce a labyrinth of channels through which the water is circulated.

As with air-based systems the sources of water-cooled personal conditioning very much depends on the design and performance of suitable supply systems. Two approaches have been made, one based on a vapour-cycle refrigeration unit and the other based on the use of thermo-electric devices.

The main advantage of vapour-cycle systems is that they usually have greater cooling capacity (up to 300 watts) but they are more complicated and therefore more expensive and prone to unserviceability. In contrast the thermo-electric systems have more limited cooling capacity for equivalent size (150 watts of cooling in ambients of 40°C is a reasonable design case) but are likely to prove less expensive and more reliable. Both systems can be run on electrical power supplies only and can therefore be made independent of engine power providing ground power supplies are available.

PROTECTION AGAINST COLD

The time-honoured method for providing cold protection is the wearing of adequate clothing insulation and this has not presented any serious difficulties to helicopter aircrew except in the case of hands and feet. For exceptionally cold conditions the feet can be protected with Mukluks and these are compatible with most foot operated controls. The hands are more difficult for nobody has solved the basic incompatibility between adequate hand insulation and the maintenance of sensitivity and dexterity necessary for flying a helicopter.

Whole body electrically heated suits have been developed and provide about 200 W of heating. So far these have not received any widespread service application. However, electrically heated gloves and socks have been used more extensively in helicopters, especially gloves, and most UK naval helicopters are fitted with appropriate supplies and controllers. Current UK electric gloves provide about 25 W to each hand and lead to only a small loss of dexterity.

If water-conditioned suits or vests become widely used to provide cooling in the chemical defence environment they will, of course, also be available as heating garments for use under cold conditions. It is a comparatively simple problem to provide suitable heating supplies.

IMMERSION PROTECTION

Perhaps the most significant cold hazard facing a helicopter crew is the risk of ditching in cold water. Without adequate immersion protection a pilot in normal flying clothing may not survive for more than an hour in water at less than 10°C (Ref 6). Mathematical modelling techniques have now made it possible to provide reasonably accurate predictions of survival time (calm water) under various conditions of water temperature and immersed clothing insulation and an example is shown in Figure 4. Such information makes it possible to make reasoned choices of protective clothing based on estimates of likely rescue time. Generally speaking such assemblies will include an effective immersion suit (anti-exposure suit) whenever flying over water at less than 10°C. In specifying the performance of such immersion protection it is recommended that this be done in terms of the required immersed insulation level (measured in water) together with the duration for which this level of insulation must be maintained., The latter will determine the maximum allowable rate of leaking.

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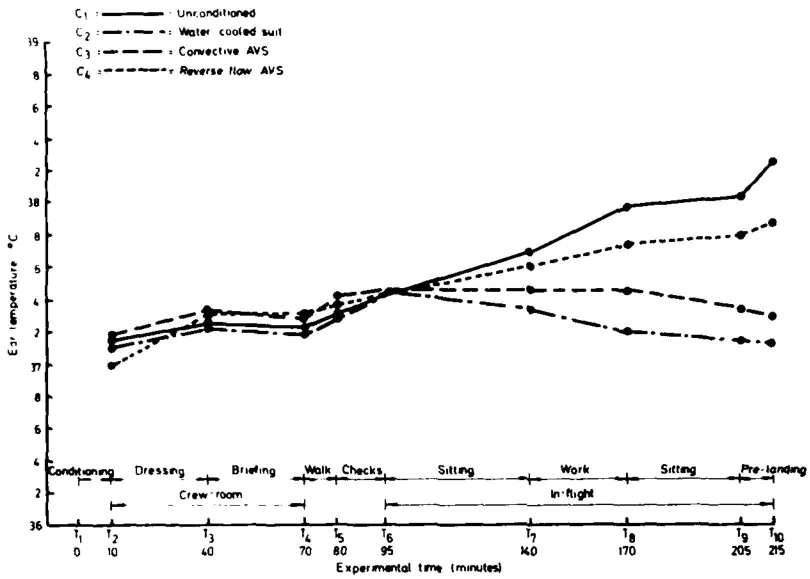

Figure 1. Mean ear temperatures for four conditioning systems (low level clothing).

Figure 2. A whole body Liquid Conditioned Suit.

Figure 3. Liquid Conditioned Vests of Two Designs.

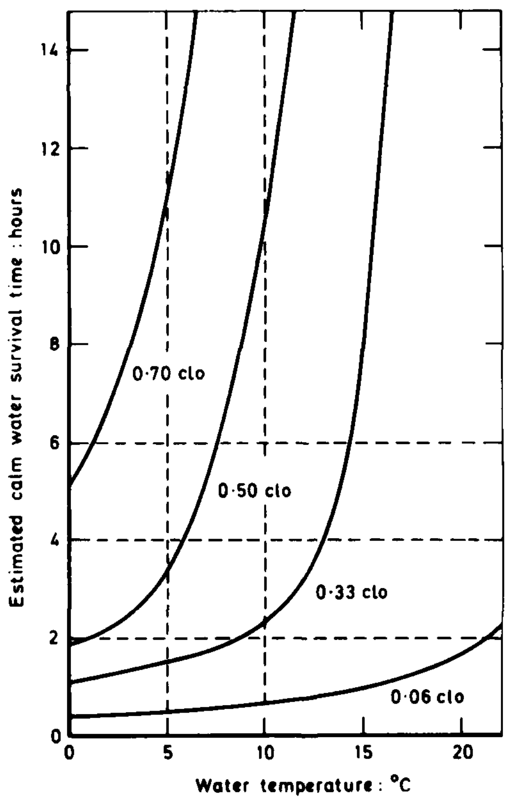

Figure 4. Estimated calm water survival times plotted against water temperature for thin individuals (approx. 10th percentile mean skinfold thickness) wearing various levels of immersed clothing insulation. The lowest curve is for lightweight summer clothing only. The other three are for assemblies including an immersion suit with increasing thicknesses of clothing worn beneath. (This figure was kindly provided by Professor Eugene H Wissler of The University of Texas at Austin, USA).

MEDICAL ASPECTS OF HELICOPTER SAFETY AND CRASHWORTHINESS

by

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SUMMARY

Helicopters are being used in increasing numbers for military operations in countries throughout the world. In the U.S. Army, helicopters comprise approximately 94 percent of the active fleet. While medical considerations for helicopter operations are much the same as for fixed wing operations, there are some differences of emphasis that will be reviewed.

A review of the past 5 years' accident experience reveals that 80 percent are attributed to human error. It is shown that crew error is never a sufficient explanation for an accident. The relationship of errors to system deficiencies is established through human factors analysis. Once identified, appropriate measures can be instituted to correct these deficiencies.

Since current operational helicopters are not equipped with systems for in-flight escape, crashworthiness is a key issue in their design. Principles of helicopter crashworthiness are reviewed, and the means for deriving these principles from crash injury analysis is discussed.

INTRODUCTION

Due to its maneuverability and versatility, the helicopter is being employed in rapidly increasing numbers for military operations in many countries. In the U.S. Army, helicopters comprise about 94 percent of the Active Army aircraft fleet, and they are being used in a wide variety of roles including observation/scout, attack, transport, and medical evacuation. Although many of the medical considerations for military helicopter operations are identical to those in fixed wing operations, certain peculiarities of helicopter operations and mission produce a somewhat different spectrum of problems. This paper will concentrate on these differences and only briefly address those aspects that fixed wing and rotary wing operations have in common.

Certainly, the greatest medical hazard faced by helicopter aircrews in peacetime, and probably in combat as well, is the potential for injury in a crash. Current training and employment doctrine for helicopter operations involves a low airspeed, low altitude flight regime that significantly erodes the margin of safety inherent in higher altitude, higher airspeed operations. Nap-of-the-earth (NOE) operations require a degree of alertness and coordination by flightcrews for extended periods of time unparalleled in most other flight operations. Furthermore, NOE flight by its very nature lessens the opportunity for a successful landing in the event of an emergency. These factors, combined with the additional stress placed on crews operating with night vision goggles or nuclear, biological, and chemical protective ensembles, make accident prevention during military helicopter operations both difficult and extremely important. Additionally, if valuable human and materiel resources are to be preserved, crashworthiness principles are of utmost importance in helicopter design. These two areas, accident prevention and injury prevention in military helicopter operations, will be the primary topics addressed in this paper.

U.S. ARMY ACCIDENT EXPERIENCE

In order to prevent accidents, it is essential to have an understanding of what causes them. In this section, U.S. Army accident experience from FY 1978-1982 will be briefly reviewed.

Figure 1 depicts the U.S. Army mishap rates for all Class A, B, and C accidents for FY 1972-82. These are accidents which involve property damage estimated to be in excess of $300 or an injury which caused an individual to miss one or more days of work.[4] The accident rate per 100,000 flying hours has remained relatively constant throughout the period with only minor fluctuations about the mean from year to year. This has occurred in spite of considerable effort on the part of the U.S. Army to reduce this accident rate.

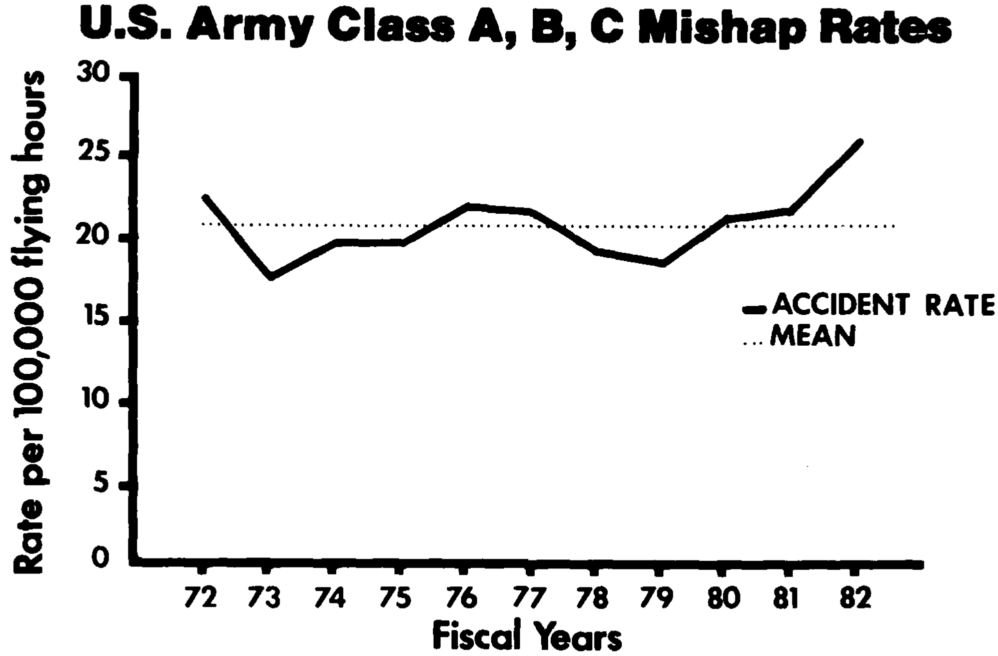


FIGURE 1.--Class A, B, and C Accident Rates, FY 1972-82

ACCIDENT CAUSE FACTORS

For reporting purposes, the primary cause of each accident in the U.S. Army is assigned to one of three major categories: human error, materiel malfunction/failure, and environmental factors, depending on which factor was determined to be most important in causing the accident. It should be noted that more than one cause factor may be involved in an accident. Official Army guidelines define a human error as job performance which deviated from that required by the operational situation.[3,14] The job performance required by the operational situation is that stipulated by formal or on-the-job training, standard operating procedure, other directives, or what is generally accepted as common practice. An aircraft system, component, or part is considered to have failed or malfunctioned when it (1) becomes completely inoperable, (2) is still operable but no longer is able to perform its intended function satisfactorily, or (3) has deteriorated to a point where it is unreliable or unsafe for continued use. Environmental conditions are considered to be a cause factor when they adversely influence the performance of personnel or materiel and thereby contribute to an accident.

The distribution of major cause factors for the period FY 1978-82 for all Class A, B, and C accidents is shown in figure 2. Human error was identified as the primary cause factor in 71 percent of these accidents and materiel failure and environmental conditions were identified in 14 percent and 15 percent respectively. Clearly, the major immediate cause of accidents is attributed to human error.

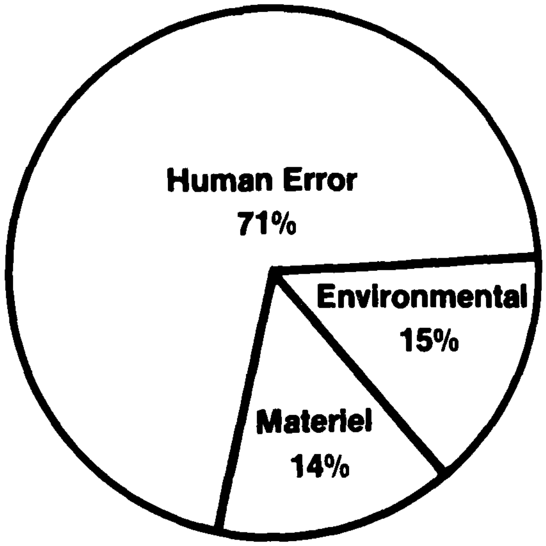


FIGURE 2.--Primary Accident Cause Factors

HUMAN ERROR ACCIDENTS

When human error accidents were analyzed separately, it was found that 80 percent were directly attributable to crew error, 10 percent to supervisory error, and 5 percent to ground crew error (figure 3). Figure 4 shows the trend in human error accident rates over the 5-year period studied. There was a significant increase in human error accidents during the period covered which was directly related to a proportionate increase in accidents attributed to crew error since supervisory and ground crew accident rates have remained constant. It is interesting that the mean age of crewmembers involved in crew error accidents was 31 years and the average flight time was approximately 1,400 hours. Therefore, this category of accidents is not necessarily occurring with young, inexperienced aviators, but with older, more experienced aviators as well.

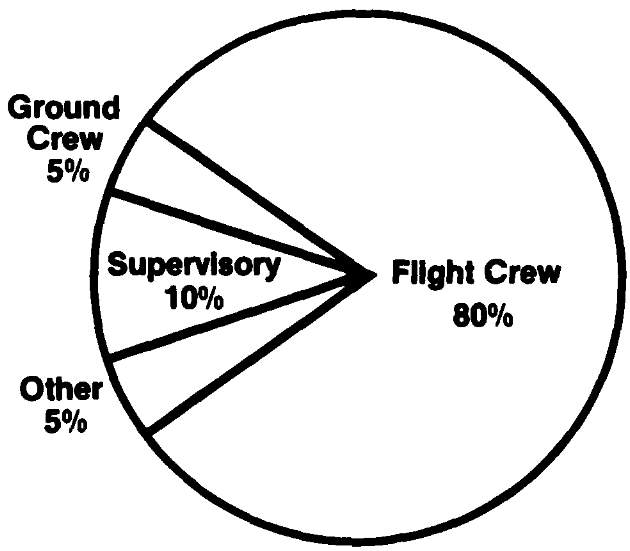
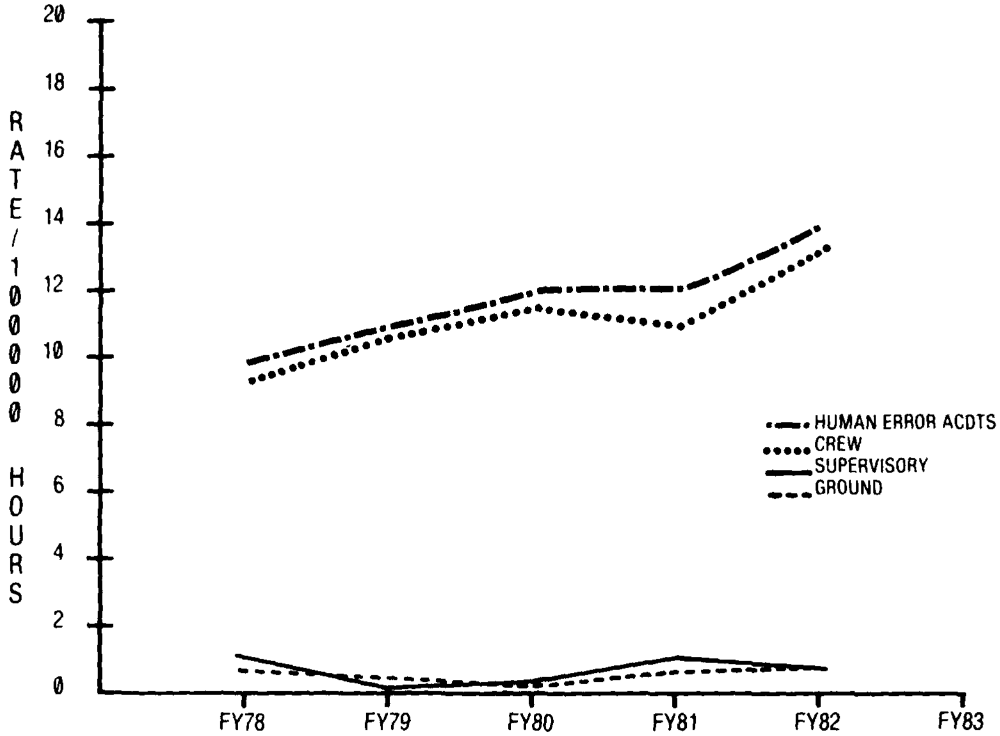


FIGURE 3.--Human Error Accident Cause Factors



	FY78	FY79	FY80	FY81	FY82	FY83
TOTAL A.B.C. ACDTS	283	269	331	354	354	
W/ONLY HUMAN ERRORS	140	158	184	198	199	
PERCENT OF TOTAL	49%	58%	58%	56%	56%	

FIGURE 4.--Trends in Human Error Accident Rates

SYSTEM INADEQUACIES

As stated, the vast majority of accidents can be attributed to human error and, by far, the most frequently cited group is the flightcrew. However, it should be stressed that this analysis has only addressed the immediate cause of an accident--an individual or group of individuals made an error that caused the accident. To stop at this superficial level of analysis would be simplistic since it fails to identify why the error was made. People make errors within the system in which they operate, and it is the deficiencies in the system that predispose them to make these errors.

In order to prevent recurrence of errors, the specific system deficiency or deficiencies that set the stage for the error must be identified and corrected. To simply place blame on the crewmember who made the error, which is the historical approach, is counterproductive since this will not correct the predisposing problems. Figure 5 depicts the accident model utilized by the U.S. Army.[3] There are 12 areas outlined which are basic to the Army aviation resource management system. When one or more of these elements is deficient, it imposes an overload on personnel or materiel. When people cannot adequately compensate for the system imposed overload, errors occur. Similarly, when materiel is not properly maintained or is overstressed through improper use, inadequate design, or inadequate manufacture, it will malfunction or fail. As suggested in figure 5, most human error, materiel malfunctions/failures, and environmental factors do not lead to an accident; however, a small portion will. Therefore, analysis of the "close calls" and "near misses" usually are just as important as analysis of actual accidents. Both are caused by underlying system deficiencies or inadequacies that need to be identified and corrected.

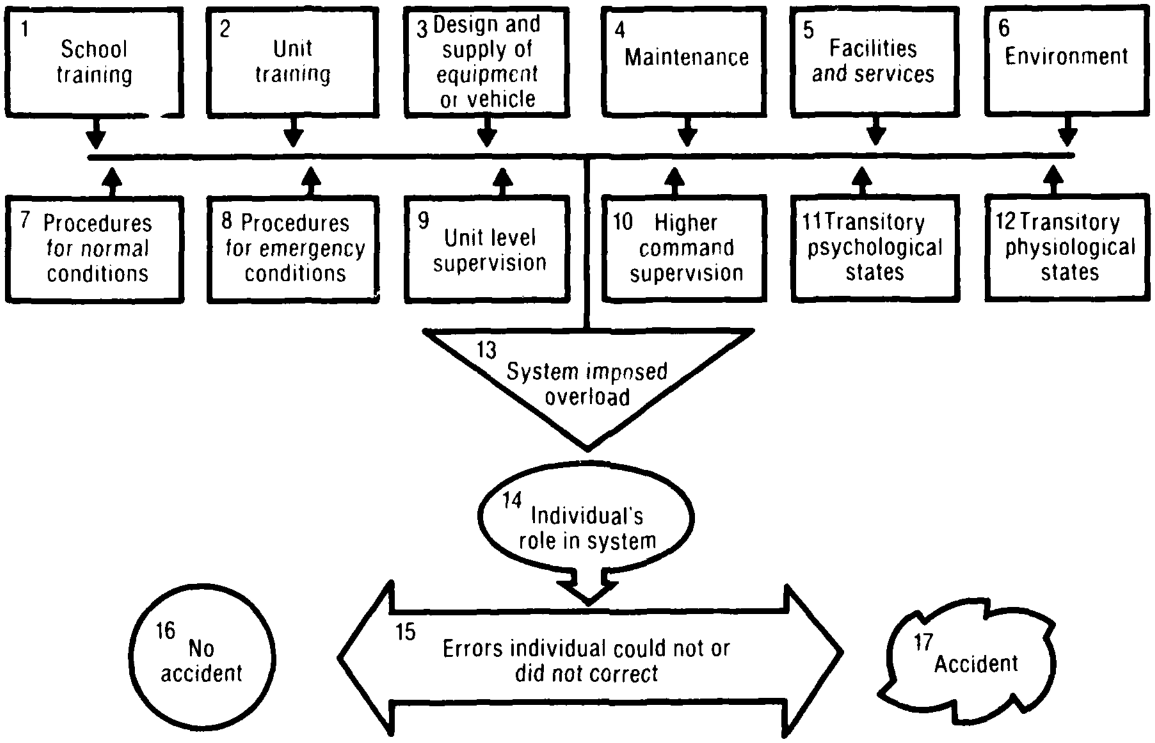


FIGURE 5.--U.S. Army Accident Model

Table I lists the five system deficiencies that accounted for 71 percent of all human error accidents during FY 1978-82. Psychological factors represented in item 11, figure 5, involve violations of procedures or generally accepted practices as a result of lapses in self-discipline such as inappropriate motivation, lack of concentration, poor judgment, or overconfidence. The remaining problem areas identified in figure 5 are self-explanatory.

Table I. Aircraft Accident System Problems

AREA	NUMBER	PERCENT
Psychological factors Motivation Attention Judgment Overconfidence	274	40.4
Unit training	91	13.4
Written guidelines	52	7.7
Equipment design	43	6.3
Maintenance	25	3.7
Total	**485**	**71.5**

The interesting conclusion suggested by this analysis is that more than half of the human error accidents were the direct consequence of inadequate training or lapses in operator discipline. These two factors are under the direct control of the unit level commander. For this reason, the potential exists for major improvement in the accident rate by stressing training and supervision of personnel at the unit level. Commanders need to be made aware of specific problems so that they can take appropriate corrective action.

CRASH INJURY ANALYSIS

BACKGROUND

Inherent to any military aviation operation is the inevitable fact that crashes will occur either through accident or enemy action. Consequently, a comprehensive safety program should not only focus on accident prevention but should also emphasize injury prevention in the event of a crash.

Tactical military fixed wing aircraft usually employ means of in-flight escape to prevent injury in the event a crash becomes inevitable. To date, a functional system for in-flight escape from disabled helicopters operating in NOE conditions has not been implemented. This is primarily because there is very little reaction time available to initiate escape at such low altitudes. Occupants of a disabled helicopter must ride it to the ground. Nevertheless, experience has shown that the vast majority of U.S. Army helicopter crashes can be survived if the helicopter is designed to be crashworthy and occupants are provided with effective life support equipment (LSE). This has been demonstrated rather dramatically in crashes of the U.S. Army UH-60A Black Hawk, the first helicopter built to rigorous crashworthiness specifications.

Concepts for crashworthiness designs and for effective LSE are, in large part, developed through use of data from aircraft accident investigations. The key to this effort is the crash injury analysis. This process focuses on the injury or lack of injury sustained by occupants involved in an accident and the relationship of impact kinematics, structural deformation of the aircraft and interior components, and functioning of LSE to the production or prevention of their injuries. The process of injury investigation is not particularly complex; however, it does require careful attention to detail and expertise in medicine, engineering, and biomechanics.

It is unfortunate that in most accident investigations crash injury analysis receives very little attention. Most of the effort in investigations tends to be directed toward establishing the cause of the accident. However, if injuries are to be prevented, it is also essential to establish injury cause factors. Furthermore, in today's tight fiscal climate, funding for crashworthiness improvements is not won easily, and substantial epidemiological data supporting a need for the recommended changes are frequently required. This is particularly true in military aircraft design since building a crashworthy aircraft usually adds a weight penalty and increases the total cost of the aircraft without improving apparent operational effectiveness. It is sometimes difficult to convince military planners that the payoff for building a crashworthy aircraft is realized through preservation of valuable human and materiel resources in the event of a crash. These are long-range goals that frequently are subverted in the effort to produce an aircraft on schedule and on budget.

CONDUCT OF CRASH INJURY INVESTIGATION

The crash injury investigation takes place within the context of the general accident investigation and usually is conducted by the same team members. Although it may be conducted by a separate team, few organizations can afford such a luxury. Nevertheless, for the purposes of this section, the crash injury investigation will be discussed as a separate entity with the assumption that the general investigation is being conducted concurrently.

As in any investigational process, some degree of preaccident planning and coordination is required. It is important for the investigator to become as familiar as possible with the design and mission of any aircraft for which he may have accident investigation responsibility. Table II lists some of the areas that are probably most important for injury analysis, but is by no means all inclusive. The more known about the design, mission, and previous crash performance of an aircraft, the better prepared a person will be to participate in an accident investigation involving that type of aircraft. Of course, the more familiar one becomes with an aircraft, the more cautious he must also be not to adopt any preconceived conclusions about a particular accident without substantiating evidence. An additional concern in preaccident planning is coordination with all local civil and military organizations that may become involved in an accident investigation. This includes fire-fighting and rescue personnel, hospitals, coroners or medical examiners, law enforcement agencies, and aviation safety personnel.

TABLE II. Design and Mission Factors for Crash Injury Analysis

1.	Landing gear--type, load capability.
2.	Main structural members--load capability.
3.	Crushable structure--particularly of floor.
4.	Fuel system--type, tank location, fuel line location.
5.	Seating--type, load capability, location, orientation.
6.	Restraint--type, load capability.
7.	Potentially hazardous objects within personnel strike envelope.
8.	Potential escape routes.
9.	Personal LSE--how functions, capability.
10.	Type missions flown.
11.	How A/C performed in previous crashes.
12.	High mass item retention capability.

From the standpoint of the crash injury investigation, there are two major recurrent problems that usually can be avoided by preaccident coordination. The first is the problem of jurisdiction over the bodies in a fatal accident. Obtaining a complete forensic autopsy is, of course, essential to the crash injury investigation, but one cannot assume that autopsy authorization will be given without prior agreement. The specific details of obtaining authorization vary markedly from country to country, so it is essential that investigators coordinate with local authorities to eliminate confusion or dispute when an accident occurs.

The other recurrent problem relates to removal of fatalities without documentation of their positions in relation to wreckage or other surroundings. This information can be valuable in determining mechanism of injury and is easily documented by photographs. Consequently, all crash rescue personnel should be made aware of the importance of this information and how they can help preserve it. On the other hand, it should be stressed that photographs are secondary to rendering aid, and if it is necessary to move a victim in order to determine his condition or to administer aid, it should be done without hesitation. In any case, crash rescue personnel should be interviewed as soon as possible after the accident to record their recollections of location and position of all victims, both survivors and fatalities. When bodies are removed, all clothing and equipment should be left in place for documentation and analysis at autopsy.

INJURY IDENTIFICATION

The initial step in crash injury analysis is to identify and document all injuries for each individual involved in the crash. To simply obtain copies of medical records usually is not sufficient. It is important to realize that injuries which are not clinically significant such as external contusions, abrasions, and minor lacerations are rarely documented in the emergency room or admissions records. Furthermore, even when injuries are clinically significant, they are rarely described in sufficient detail for the injury investigator to make an accurate assessment of injury mechanism. Consequently, the collection of accurate and detailed injury information usually will require the personal intervention of an accident investigator.

The type, location, distribution, and depth of all external body wounds should be described fully. Photographs should be taken for future reference. Such documentation will aid in the determination of restraint system use and adequacy, helmet and other LSE failure modes, and in the identification of impacting or impacted objects.

The nature of all internal injuries should also be described as to type, location, distribution, and potential mechanism. Here it is useful to obtain copies of radiographs and to interview the surgeon in the case of all repaired soft tissue lesions. Operative reports frequently will not describe lesions in detail, and the sooner post-operatively the surgeon is interviewed the better his recollection will be. Such an approach may seem overly zealous, but the information obtained frequently is useful in differentiating between impact and acceleration injuries and

in determining the direction and magnitude of forces applied to the body. An additional benefit is that such detailed information provides epidemiological data that when correlated with kinematic data can be used to determine human tolerance limits. These estimates can then be applied to the design of future aircraft and LSE.

Most of the above discussion applies to survivors of the crash, but the same general principles apply to all fatalities. For example, it cannot be assumed that an appropriate autopsy will be conducted on all crash fatalities. It is imperative that the investigator immediately resolve any problems regarding jurisdiction over the remains and obtain authorization for the autopsy. Once these questions have been resolved, it is important to coordinate with the pathologist designated to conduct the autopsy to insure that all necessary data are obtained and documented. It should be realized that not all pathologists are trained in forensic pathology, and, unless specific needs are made clear before the autopsy, essential data may not be obtained.

In general, the data needed from an autopsy are the same as for a survivor. The body should be brought to the morgue fully clothed and full-body photographs taken to document the state of the garments. Full-body radiographs also are essential with additional views taken as necessary to document skeletal damage. Areas which should receive special attention are the extremities and the spine. At autopsy, all external wounds should be documented and explored. Any debris removed from external wounds should be carefully labeled for later identification. Frequently, aircraft parts will be found in external wounds and such information will help in determining the mechanism of that particular injury.

Internal examination is routine, but should be thorough and inclusive with appropriate specimens taken for microscopic examination and toxicology. All abnormalities, no matter how minor, should be documented. Physical examination of the joints is useful in determining soft tissue injury when rigor mortis is not present. When internal derangement of the joints is suspected, dissection will identify ligamentous or skeletal failures. Likewise, dissection is helpful in identifying unsuspected fractures of the spine, and posterior exploration may reveal previously unsuspected ligamentous or even bony injuries which can contribute to an understanding of spinous system failure modes. Thorough central nervous system (CNS) examination is equally important since the large accelerations and rapid onset rates experienced in crashes may cause significant derangements of the CNS, particularly in the brain stem, which may not be obvious from a cursory examination. It is important to conduct an internal examination of the upper respiratory system when fire was present to explore for evidence of soot. Such evidence will help differentiate whether the individual died of impact or thermal injuries.

Clearly, this section is not intended to be a complete guide on methods of injury identification, but rather a guide to some of the general principles involved and to some of the major areas where problems are encountered. Further information can be found in several excellent references.[6,10,11] The major point to appreciate is that the vast majority of physicians (including pathologists) are not cognizant of the basic principles of biomechanics and mechanisms of injury. They are primarily concerned with the treatment of the injured and will, therefore, not obtain the detailed description of injuries required for an injury investigation without close personal involvement of the injury investigator. It generally is more effective for this liaison to be carried out by a medical officer versed in the principles of injury analysis (biomechanics of injury), but this is not essential. The principal objective is to insure some member of the investigation team effects this coordination early in the investigation so that important data are not irrevocably lost.

CRASH KINEMATICS

Although injury identification is essential in crash injury analysis, it is not all encompassing. The remainder of the investigation is directed toward determining cause or mechanism of injury. Essential to this process is an accurate determination of crash kinematics and forces to which the aircraft and its occupants were subjected. It is beyond the scope of this paper to discuss the derivation of these data but several points should be stressed.

Human tolerance to acceleration is dependent upon (1) direction of applied forces, (2) magnitude of forces, (3) rate of onset of loading, and (4) type of restraint and seating.[18,19] Clearly, these are parameters that are directly related to the crash kinematics and underscore the need for determining these parameters. Additionally, kinematic data may be used to estimate the body motions each occupant may have experienced during the crash sequence. This information is useful in identifying structures most likely to have been responsible for a specific contact injury or in predicting the biomechanics of a particular acceleration injury. The latter point is particularly important for spinal injuries where it is important to determine whether an injury was caused by hyperextension, hyperflexion, lateral flexion, compression, rotation, or a combination of these mechanisms. Such knowledge allows designers to develop more efficient seat and restraint systems.

Finally, a word of caution about determining acceleration levels in a crash. In many cases, there has been a tendency for crash injury investigators to use injuries sustained in a crash to estimate the force parameters experienced in that crash.

This approach may be useful in certain circumstances; however, in general, deformation of aircraft structure, ground scarring, and empirically determined velocity parameters are much more accurate for this purpose. This is because human tolerance limits vary tremendously from individual to individual depending on the subject's age, sex, physical condition, seat and restraint configuration and adjustment, and natural human biological variability. Consequently, injury data are best used to substantiate or refute parameters calculated from other sources whenever possible.

INJURY CORRELATION

Once injuries, kinematics and crash forces have been determined, actual injury mechanisms may be postulated. As previously discussed, injuries may be due purely to acceleration loading without impact with aircraft or outside structures. Acceleration injuries are confirmed when there is no physical evidence of contact loading obtained from examination of the subject, the aircraft structure, and clothing or LSE worn by the subject. The majority of injuries sustained in helicopter accidents involve contact with structure due to deformation of the aircraft, inadequacy or improper use of restraint systems and seats, or failure of designers to provide adequate clearance between potentially hazardous objects and properly restrained occupants. In such cases, it is vital to examine the aircraft wreckage to identify failure modes of seat or restraint systems and to identify potentially impinging structures. This information may then be correlated with injuries or damage to personal LSE (helmet and other flight clothing). In many cases there will be insufficient data available to make positive correlations, but the attempt should be made. Postulated injury mechanisms should be consistent with the physical evidence as well as with estimated crash kinematics and crash forces. Descriptions of injury mechanisms placed in accident reports should be concise, but of sufficient detail for medical analysts and engineers to fully appreciate the cause of the injury.[9]

DATA STORAGE AND ANALYSIS

It is important for authorities charged with the overall system of military accident investigation and, indeed, the investigators themselves to realize that data derived from any particular accident investigation will rarely have much direct impact on accident or injury prevention. The trends in accident and injury causation identified through multiple investigations will have the greatest influence on the total aviation safety program. For this reason, all accidents should be thoroughly investigated by trained and experienced investigators, the data recorded in a standardized format, and stored in a single centralized repository for ready access. Additionally, these data need to be routinely analyzed by a multidisciplinary team of experts in operations, engineering, medicine, human factors, and other allied fields to identify trends that may be important in accident prevention and future crashworthy aircraft designs.

The U.S. Army has established a central agency, the U.S. Army Safety Center (USASC), which is responsible for accessing and analyzing all accident data for both aviation and ground accidents. USASC also provides investigation teams for all accidents where there is a fatality, the vehicle is damaged beyond repair, or total property damage exceeds $500,000. The organization of USASC and its association with Department of Defense medical organizations was detailed in a previous AGARD publication.[9]

PRINCIPLES OF CRASHWORTHINESS

BACKGROUND

The basic principles of crashworthiness were established in the 1940's, but have not been widely applied in either civilian or military aircraft designs. The notable exceptions to this have been some agricultural aircraft and, more recently, modern U.S. Army helicopters. The failure of manufacturers to incorporate these design principles into production aircraft stems largely from the weight and cost penalty associated in building crashworthy aircraft and the refusal of regulatory authorities to require their adoption. Nevertheless, over the past 20 years, the U.S. Army has come to realize that, although production costs of a crashworthy helicopter may be greater and there may also be some weight penalty, these initial disadvantages are more than compensated over the life cycle of the aircraft through injury reduction and, to a lesser extent, increased repairability of the aircraft after a crash.[1,8,17]

The current crashworthiness standards to which all U.S. Army helicopters now are designed are specified in Mil-Std-1290, "Light Fixed- and Rotary-Wing Crashworthiness."[13] This standard is based on the principles outlined in the "Aircraft Crash Survival Design Guide" which is a compendium of crashworthiness design principles that were derived through detailed study of data from crash injury investigations.[20] The reader is referred to these and other references for detailed information as this paper will only review some of the basic principles.

DESIGN CRITERIA

Mil-Std-1290 generally addresses five basic areas that must be considered in designing a helicopter to provide an adequate level of protection for the occupants in the event of a crash:

a. Structural crashworthiness. Insuring that the cabin structure has the appropriate strength and stiffness to maintain a livable volume for the occupants throughout the crash sequence and that the seat and restraint attachments remain intact.

b. Occupant load limitation. Insuring that the loads on the occupants remain within the human tolerance range through the use of crushable structure and load limiting landing gear and seats.

c. High mass item retention. Insuring that high mass items such as the rotor blades, transmission, and engines do not penetrate occupied areas during a crash.

d. Noninjurious interior. Providing adequate restraint, padding, and placement of interior items to prevent injury from flailing during a crash.

e. Postcrash protection. Providing protection from fire in the postcrash environment through containment of flammable fluids and reduction of ignition sources and through providing adequate avenues of egress for all occupants under all potential conditions.

SURVIVABILITY

Individual survivability in a crash is dependent on two major factors. The accelerative forces to which the individual is subjected must not exceed his tolerance limits and the structure must maintain a sufficient volume throughout the crash sequence in order to prevent impingement of structure on occupants. Inherent in the latter factor is that the individual must also be sufficiently restrained so that he does not impact interior structures (secondary collision) by flailing or that he is not ejected from the aircraft. In order to fulfill these requirements for the widest range of potential crashes, Mil-Std-1290 was predicated on preventing occupant fatalities and minimizing the number and severity of injuries during crash impacts of a severity up to the 95th percentile potentially survivable crash. A secondary objective was to minimize aircraft damage to the maximum extent practical up to this limit. The 95th percentile survivable design pulse was established from data collected from accident injury investigations and means that in only 5 percent of potentially survivable crashes are the loads on the occupants in excess of the design standard. Clearly, the effectiveness of this standard is only as good as the data upon which it was based. This fact underscores the importance of carrying out meticulous accident injury analyses.

Table III, derived from Carper and coworkers, reviews the 95th percentile potentially survivable crash impact design conditions currently specified by Mil-Std-1290.[2] The design pulses stated are given in terms of impact velocity change for impacts against specified surfaces with associated minimum attitude requirements. From a design standpoint, the vertical requirement is the most difficult to meet particularly because of the 30-degree roll requirement. Under these conditions, energy absorbing landing gear, crushable fuselage structure, and load attenuating seats have been required to limit loads to the occupants to noninjurious levels. For the other major axes, noninjurious loads can be maintained through judicious structural design alone. It should be mentioned that based on analysis of more recent accident data, there is a proposal to reduce the 30-degree roll requirement in vertical impacts to 10 degrees since it is now felt that this more accurately reflects actual impact conditions.

Table III Percentile Potentially Survivable Crash Impact Design Conditions

IMPACT DIRECTION (AIRCRAFT AXES)	OBJECT IMPACTED	VELOCITY CHANGE (FT/SEC)	MIL—STD—1290 CURRENT PITCH	ROLL	YAW
Longitudinal (Cockpit)	Rigid Abutment or Wall	15			
Longitudinal (Cabin)	Rigid Abutment or Wall	40			
Longitudinal (Cockpit & Cabin)	Rigid Surface	50	0	0	0
Vertical	Rigid Surface	42	+15°	+30°	0
Lateral(a)	Rigid Surface	25			
Lateral(b)	Rigid Surface	30			
Resultant Vector*	Rigid Surface	50			

(a) Light fixed-wing aircraft, attack and cargo helicopters.
(b) Other helicopters
*Note: The downward, sideward, and forward velocity components of the resultant velocity vector do not exceed 42, 30, and 50 ft/sec, respectively.

HUMAN TOLERANCE

In preceding sections much has been said about human tolerance and designing helicopters to limit loads to tolerable levels. Obviously, the subject of whole-body human tolerance to acceleration is a highly complex issue. In general, tolerance is dependent upon direction, magnitude, and rate of onset of force application as well as type of restraint system used and the orientation and design of seats. In selecting tolerance levels for design purposes, the degree of tolerance also needs to be stipulated. That is, should a system be designed to prevent all injury for a given input condition, or are certain specified levels of injury acceptable? The ultimate tolerance limit is, of course, that which causes fatal injuries, and for certain impact conditions must be accepted. It is impossible to build an aircraft that will protect occupants under all conceivable impact conditions.

Current U.S. Army design criteria are based on the upper limit of tolerable acceleration (no injury) established by Eiband in 1959.[5] The "Eiband Curves" represent a compilation of all known human tolerance data for acceleration applied along each of the major axes of the seated and restrained individual. Figure 6 is an example of the Eiband Curve for the $+G_z$ direction which is the primary direction of force application in most helicopter mishaps. This graph is a plot of acceleration versus duration for a specified input pulse shape, depicted in the lower right corner of the graph. The graph is divided into four tolerance regions which can be described as follows:

a. Voluntary exposure.

b. No injury.

c. Moderate injury.

d. Severe injury.

As stated above, current Army design criteria are based on the limit curve separating the region of no injury from the region of moderate injury for all impacts up to the 95th percentile survivable impact (42 ft/sec vertical velocity change). For general reference, the total duration of the pulse in most helicopter crashes is usually between 10 and 100 milliseconds.

As an example of how these data are used in aircraft design, the current Army seat requirement, Mil-S-58095, requires that vertical accelerations transmitted to the individual be limited to 23 G for time durations exceeding 6 milliseconds.[12] Referring to figure 6, it can be seen that 23 G for 6 milliseconds falls at the upper limit of no injury. It should be pointed out, however, that these are average data

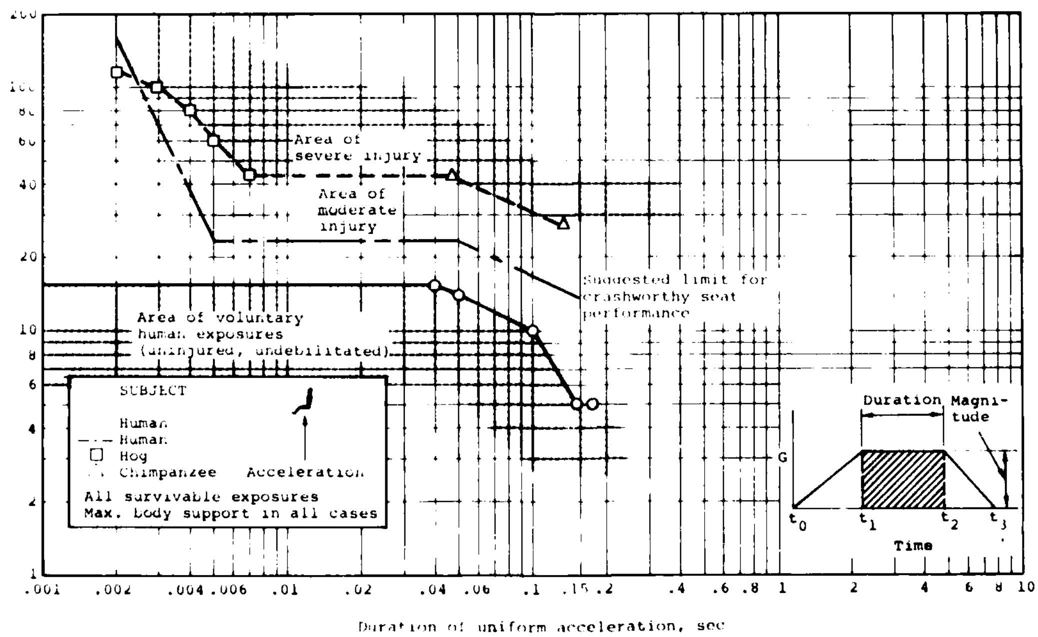


FIGURE 6.--Eiband Tolerance Curve for Vertical ($+G_z$) Accelerations

based on relatively few observations. Individual tolerance limits will deviate markedly from the average depending on the subject's age, sex, physical condition, and a host of other parameters. Consequently, even at these conservative design levels, a small proportion of individuals may be seriously injured although the loads were limited to the design levels. Nevertheless, these data are the best available, and, based on the crash experience of the U.S. Army UH-60A Black Hawk helicopter, they are relatively accurate, at least for the young, healthy aviators so far exposed to crashes in this crashworthy helicopter.

Although the discussion of crashworthiness has centered around specifications for aircraft design, the same principles can be applied to the development of personal protective equipment such as helmets. As an example, through over 10 years of study of helmets worn by occupants involved in U.S. Army helicopter crashes and the correlation of these data with crash injury data, failure modes of the current flight helmet have been identified and new design criteria established to reduce injury.[7,15,16] The new Army integrated flight helmet will incorporate these new impact criteria with the result of substantially reducing an estimated one-third of all head injuries now sustained in helicopter crashes. As with crashworthiness design criteria, these new helmet design specifications were achieved only through long-term crash injury investigations and rigorous epidemiological analysis.

CONCLUSIONS

1. Medical problems encountered in rotary wing flight operations may be appreciably different from those encountered in fixed wing operations.

2. A review of U.S. Army accidents covering a 5-year period has revealed that the majority are attributed to human error. These errors are due to system deficiencies that can be identified through appropriate human factor investigations and corrected through command channels. Crew error is never a sufficient explanation for an accident.

3. Since practical in-flight escape systems for helicopters operating in NOE conditions are yet to be developed, it is essential to design crashworthy aircraft if valuable human and materiel resources are to be preserved in the event of a crash.

4. Crashworthy designs are developed primarily through careful epidemiological analysis of injuries incurred in accidents. Consequently, greater emphasis needs to be applied to crash injury analysis during accident investigations.

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BACK PAIN IN HELICOPTER FLIGHT OPERATIONS

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SUMMARY

One of the major medical problems associated with military helicopter flight operations is the high prevalence of back pain reported by flightcrews. Epidemiological surveys have indicated that up to 75 percent of helicopter flightcrews complain of this affliction and that it is having a significant effect on manpower availability. The two most widely implicated etiological factors in this problem are poor posture dictated by control and seat configurations in most operational helicopters and the chronic vibration to which helicopter flightcrews are subjected. This paper reviews the epidemiology and etiology of back pain in helicopter aircrews and discusses potential means for treatment and prevention.

INTRODUCTION

Early in the history of helicopter flight, it became apparent that helicopter flightcrews complained of a remarkably high incidence of back pain compared to their fixed wing counterparts. Over the past 25 years, the high prevalence of back pain in helicopter flightcrews has been documented in numerous reports.[4,5,6,14,17,20] Most of these studies have reported prevalence rates in excess of 50 percent, and many have reported prevalences exceeding 75 percent, apparently depending on the group studied. Based on these data, it has become clear that there are certain factors unique to helicopter flight operations that induce a high rate of back pain in crewmembers. This paper discusses the typical pain syndrome reported by helicopter crewmembers, factors influencing this condition, and possible etiologies of the back pain reported. Recommendations for prevention and treatment are also discussed.

EPIDEMIOLOGY AND SYMPTOMATOLOGY

In a recent survey of 802 U.S. Army aviators, 72.8 percent reported having experienced one or more episodes of back discomfort while flying helicopters over the preceding 2 years.[19] Forty-eight percent of these stated that they experienced discomfort on more than 25 percent of their missions and 26 percent reported symptoms on over half of their flights (figure 1). Only 16 percent of the respondents stated that they had symptoms on more than three-quarters of their flights. The average duration of flight required to produce back symptoms for these respondents was 88 minutes, which may explain the wide variation in reported frequency of symptoms. These data suggest that the onset of back symptoms in a particular individual is a threshold phenomenon that requires a certain minimum duration exposure to helicopter flight. Since many helicopter missions are relatively short and do not exceed this minimum threshold, pilots will not necessarily suffer back discomfort on every flight. Delahaye et al. have suggested that the onset of symptoms may also be influenced by the difficulty or intensity of the mission.[4]

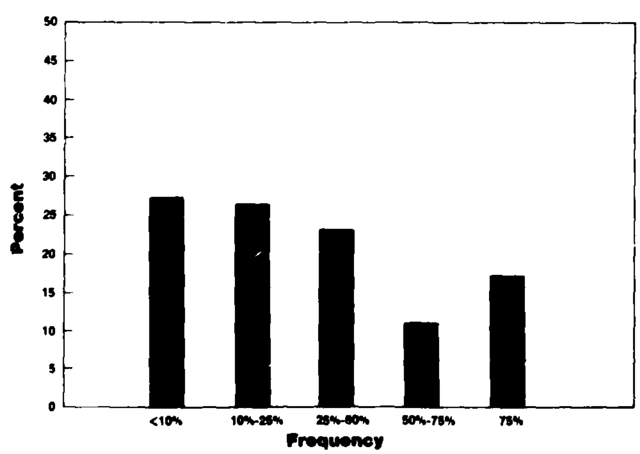

Figure 1. Frequency of missions causing back discomfort based on a survey of 802 U.S. Army aviators.

The discomfort helicopter pilots typically describe is a dull ache confined to the lower back and/or buttocks. Radiation into the lower extremities is rare. In the U.S. Army survey, 70 percent of the respondents reported that they most frequently experienced pain in the lower back, and 16.6 percent complained most frequently of pain in their buttocks (figure 2). Relatively few aviators reported symptoms in other regions of the back or the neck. Once the pain begins on a particular flight, it may continue to increase in intensity throughout the flight or reach a certain intensity and then remain stable. It is not relieved with changing position or by relinquishing the controls to a copilot. In all cases, the afflicted aviators do not begin to notice relief of their symptoms until after the termination of the provoking flight. Some aviators have reported that they can delay the onset of discomfort by placing a rolled-up jacket or inflatable cushion in the small of their backs to provide increased lumbar support.

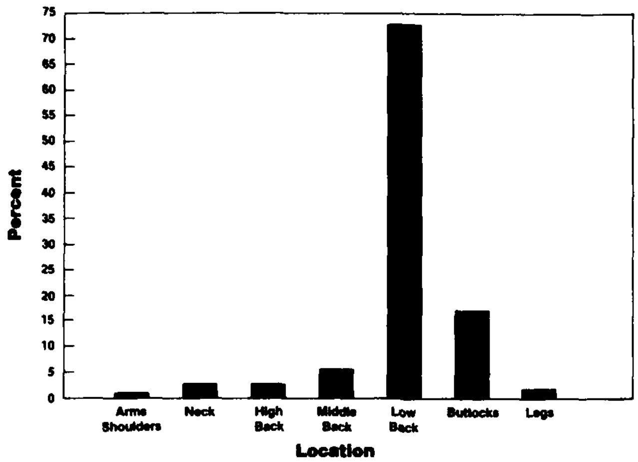

Figure 2. Distribution of locations of back discomfort from U.S. Army survey.

In the U.S. Army survey, pilots were asked to rate the intensity of the discomfort they experienced on a scale from one to nine, with one representing no pain and nine representing excruciating pain. Figure 3 shows a frequency distribution of their responses. The modal pain intensity was 3 with a mean response of 4.2. Therefore, the intensity of the reported pain can be generally classified as mild to moderate. Although the reported intensity of the pain was not severe, it was significant enough that 28.4 percent of afflicted aviators admitted to rushing through missions due to their back pain and 7.5 percent stated that they had refused missions because of back pain. Consequently, it is clear that back pain in U.S. Army helicopter pilots is a significant problem that is undoubtedly having an adverse effect on overall operational readiness of aircrews.

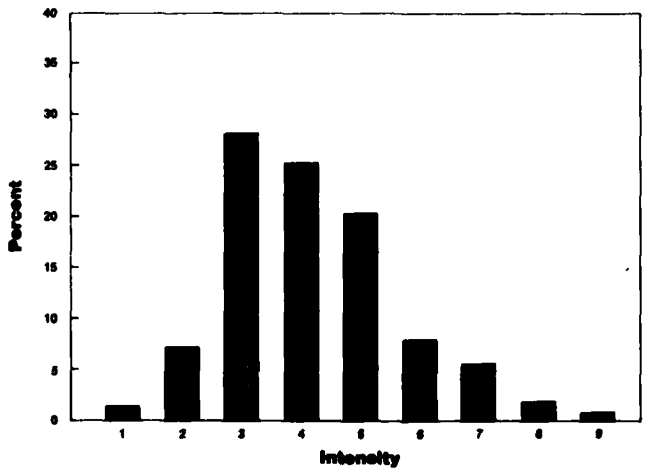

Figure 3. Frequency distribution of reported pain intensities in U.S. Army survey (1 = no pain; 2 = excruciating pain).

The majority of afflicted Army aviators have reported that their symptoms begin to improve immediately upon termination of the flight, and 53 percent stated that they were completely pain-free within 12 hours. However, a small portion (14.5 percent) reported having symptoms that persist for longer than 48 hours, and 8 percent stated that their symptoms may last for longer than 4 days. Based on these findings, it may be possible to separate afflicted crewmembers into two relatively distinct clinical groups--those with transient symptoms (i.e., less than 24 hours) and those with persistent symptoms (i.e., greater than 48 hours). It is tempting to speculate that the persistent pain group was comprised of individuals on a continuum progressing toward permanent pathological changes in the spine. The U.S. Army survey yielded some data that tended to support such a theory. It was shown that the pilots who reported persistent pain tended to have more flight hours and more time on flight status than the transient pain group. The intensity of the pain they reported was significantly higher than the transient pain group, they reported symptoms more frequently, and they reported a much higher incidence of numbness in the legs which may have been related to spinal nerve root compression. Therefore, it is certain that the persistent pain group was more severely afflicted than the transient pain group, but it remains to be proven that they actually progressed to their present state or that the pilots in the transient group will progress to persistent pain with continued exposure to helicopter flight. Clearly, a longitudinal, controlled study is required to determine the effects of chronic intermittent exposure to helicopter flying.

Another interesting aspect of helicopter pilot back pain is the time of initial onset of symptoms in terms of total flight hours of exposure. Most authors have found that there is a delay in intial onset of painful symptoms ranging from 300 hours to as much as 1,000 to 1,500 hours.[4] There is obviously considerable individual variation which Delahaye et al. attribute, at least in part, to the presence or absence of pre-existing spinal lesions or congenital abnormalities.[4] The data from the U.S. Army survey show a somewhat different pattern than reported in other studies in that a delay in onset of symptoms was not as apparent. Figure 4 is a graph depicting the percentage of aviators reporting symptoms versus their total flight hours. One-third initially noted onset of symptoms within their first 100 hours of flight and half had symptoms by 300 hours of total flight time. The reason for the differences between this survey and other reported surveys is unclear but may relate to size of population sampled, type missions typically flown, or differences in aircraft.

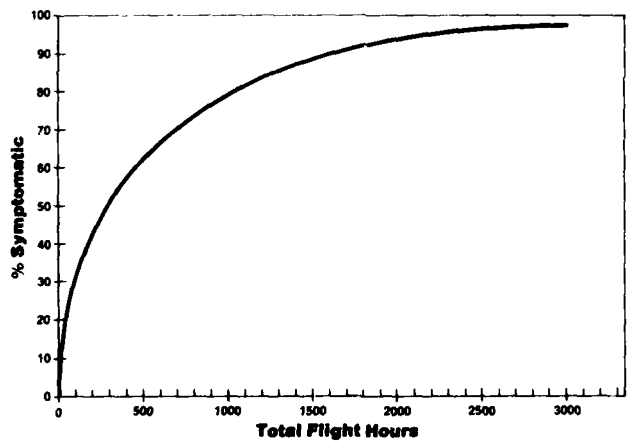

Figure 4. Percentage of aviators experiencing back discomfort as a function of total hours of flight time.

ETIOLOGY

Although the lifetime incidence of low back pain (LBP) in industrialized societies has been reported to be between 60 and 80 percent, prevalence rates rarely exceed 35 percent.[8,21,22] Clearly, the 73 percent prevalence reported by U.S. Army pilots represents a dramatic departure from the general population. Furthermore, the character and pattern of pain reported by helicopter flightcrews appears to be considerably different from that experienced in the general population. Most nonaviators report acute intermittent episodes of pain of variable duration separated by extended periods of time (frequently years) when they are completely asymptomatic. The activity or event that triggers a new episode of pain frequently cannot be identified or anticipated, unlike the rather clear pattern of onset and symptoms reported by helicopter crewmembers. It is evident that there is some factor or combination of factors associated with helicopter flight that produce a high prevalence of back pain that is rather predictable in character.

The two factors most widely implicated in the etiology of back pain in helicopter crewmembers are poor posture and exposure to vibration.[4,5,6,7,9,14,17,18,20] All authors agree that posture is a definite contributing factor, but there is still considerable controversy concerning the role of vibration in the etiology of this syndrome.

POSTURE

The posture that helicopter pilots must assume to fly is considerably different from that required to fly fixed wing aircraft. Helicopters require simultaneous input from all four extremities in order to maintain full control over the aircraft, and the types of missions flown seldom allow for relaxation from the controls. This is in marked contrast to fixed wing aircraft, many of which have autopilot systems and all of which have trim controls which permit some degree of hands-off flight. Furthermore, the seat and control configuration in most helicopters forces the pilot to assume an asymmetrical posture. Most pilots adjust their position by placing both feet on the pedals and then adjusting the seat to permit their right hand to grasp the cyclic control located between their legs while their right forearm rests on their right thigh for support. The left hand must then be placed on the collective control which extends from a position adjacent to the left side of the seat. It has been well documented that this control configuration forces pilots to bend forward in their seats and lean slightly to the left throughout the duration of the flight.[4,20] This constantly-maintained, asymmetrical position does not permit relaxation of the spinal musculature and is, according to Sliosberg, a major source of discomfort for helicopter pilots.[20]

That posture can be the source of LBP has been suggested by several other researchers.[1,3,2,5,10,12] Magora has shown that workers in occupations that force them to sit for prolonged periods, or those that involve almost no sitting, have a high incidence of LBP.[12] Keegan pointed out that the sitting position without adequate lumbar support and a trunk-thigh angle of less than 105 degrees causes a flattening of the normal lumbar lordosis.[10] This flattening creates stresses which, he notes, probably cause pain, especially for persons with underlying spinal pathology. Finally, Andersson et al. have made quantitative measurements of intradiscal pressure in the lumbar spine and the myoelectric activity of muscles of the back for various postures.[2,3] They found that lumbar intradiscal pressure was highest for unsupported sitting with the spine flexed anteriorly. Likewise, myoelectric activity increased with forward flexion of the spine, and asymmetric loading tended to increase myoelectric activity for a constant degree of anterior flexion. They concluded that increased myoelectric activity was indicative of localized muscle fatigue.

Based on these data, it is reasonable to conclude that the posture that helicopter pilots are obliged to maintain for extended periods is a major causal factor in the high prevalence of back pain noted in this population. Furthermore, the rapid resolution of symptoms for the majority of afflicted pilots upon termination of the provoking flight, suggests that their symptoms are related to muscle spasm or other transient mechanical factors rather than permanent pathological conditions.

VIBRATION

The other factor widely implicated in the etiology of back pain in helicopter flightcrews is vibration. To date, the evidence supporting vibration as a causal agent has been largely subjective and conjectural. It has been shown that most helicopters expose their occupants to vibration over a frequency range that coincides with the resonant frequency of the spinal system or one of its harmonics.[4,9,11,14,20,22] As an example, the UH-1H helicopter, the most widely used helicopter in the U.S. Army, produces a complex spectrum of vibration at the pilot stations during cruise flight. Nevertheless, the predominant components of vibration have been shown to be due to the rotation of the two-bladed main rotor system.[11] Laing has analyzed data collected from various locations in the cockpit and found the most prevalent frequencies to be at 10.8 Hz, 21.6 Hz, and 32.4 Hz, corresponding with the second, fourth, and sixth harmonic frequencies of the main rotor system.[11] The associated accelerations plus three standard deviations, which are the calculated accelerations below which 99.87 percent of the spectral data at that frequency fell, were 0.28 g at 10.8 Hz and 0.35 g at 21.6 Hz. These accelerations are relatively small, but 10.8 Hz coincides with the second resonant frequency of the spinal system of a seated human subject.[4,22] Data collected from other helicopters have also shown major components of vibration at or near the resonant frequency of the spinal system or one of its harmonics.[4,11] Consequently, many authors have speculated that chronic exposure to helicopter vibration is detrimental to the spinal system.

Nevertheless, it remains uncertain what the pathological effects of chronic, intermittent exposure to this frequency and amplitude of vibration may be over the short and long term. Most studies suggesting a higher prevalence of back pain in occupations that expose workers to vibration are purely associative studies. That vibration is, in fact, causative cannot be inferred from these studies since they fail to provide for control of the many other factors that may also contribute to a high prevalence of back pain in the particular population studied. Possible contributing factors include seating position, opportunity for changing position, and the multiplicity of variables that fall under the general category of lifestyle. Until these factors can be controlled in an experimental environment, the role of vibration in the production of musculoskeletal symptoms and pathology will remain obscure.

Shanahan and Reading recently reported the results of a preliminary study that may help shed some light on the relationship of helicopter-similar vibration to the production of the acute back symptoms that helicopter pilots describe.[19] In this study 11 pilots who reported that they usually experience back discomfort within 2 hours of flight in a UH-1H were placed in a UH-1H seat and control simulator that was mounted to a three-axis vibration table. The cyclic control of the simulator was wired so as to act as the control for a television computer game. The subjects wore standard U.S. Army flight clothing including flight helmet, and they also used standard restraint. They were instructed to position themselves as they would in an actual helicopter and to keep all extremities on the controls at all times except that they were allowed to remove their left hands from the collective for brief intervals as in actual flight.

Each pilot was subjected to two 2-hour test periods--one with simulated helicopter vibration and one without. During the test period, the subject played computer games to keep himself occupied at roughly the same concentration level as would be required to fly a helicopter. Subjects verbally reported the onset of back discomfort, and the time into the test was noted. At the completion of the test, each subject answered a brief questionnaire relating to the nature of his symptoms. Pain intensity was subjectively measured by a visual analog scale.[13,15,23]

The experimental conditions produced back pain in all 11 subjects which they described as identical to the pain they typically experience while flying helicopters. Furthermore, there was no significant difference in the time of onset or the intensity of pain for the vibration and no vibration test conditions. The authors concluded that vibration appeared to play little if any role in the acute symptoms these subjects experienced. Of course, this work is only preliminary and will require further validation, but the conclusions have definite implications for prevention of this ailment.

PREVENTION AND TREATMENT

As has been discussed, the primary etiological factor in the acute back symptoms that most helicopter pilots report is probably posture. These symptoms may or may not be aggravated by the superimposition of low frequency vibration in the range of the resonant frequency of the spinal system. Therefore, the key to reducing the incidence of the acute ailment is to improve the seat and control configuratio in helicopters to allow crewmembers to maintain better posture. This posture should be one that maintains the normal curvature of the spine and allows maximum relaxation of all opposing muscle groups. Furthermore, major body segments such as the torso (back), thighs, and arms should be supported to the greatest extent possible. Wisner has established criteria for maximum comfort for the seated individual by defining the angles between adjacent body segments that allow good relaxation of opposing muscle groups.[4] These angles are summarized in figure 5.

Angle	**Range**
a.	**15°— 25°**
b.	**15°— 35°**
c.	**85°—100°**
d.	**95°—120°**
e.	**85°— 95°**
f.	**80°—110°**

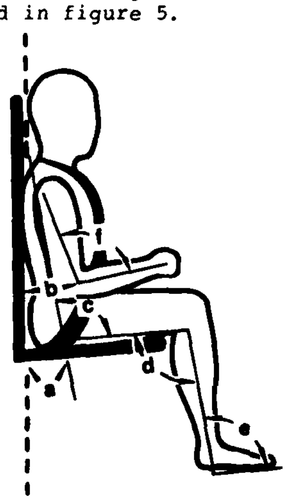

Figure 5. Optimal comfort angles proposed by Wisner.

Clearly, to build a cockpit that will permit the recommended pc tural relationships for the full anthropometric spectrum of aviators, will require a substantial departure from current design standards which, incidently, have not significantly changed since the first helicopter was designed. Seats that offer appropriate support to the back and thighs exist in other types of vehicles and could be readily adapted to helicopters. The major problem in achieving the recommended posture is that the controls must be situated in such a way that the pilot can operate them and still maintain a good, supported posture. This primarily requires that he be able to maintain a symmetrical posture without anterior or lateral flexion of the spine, and his back must remain supported by the back of the seat.[1,5,10] Various designs have been proposed, but are yet to be implemented in operational helicopters. The layout for the gunner's position on the AH-1 Cobra helicopter (figures 6 and 7) comes close to achieving these goals although the motivating consideration in this design was not pilot comfort. The AH-1 has side-mounted controls for the cyclic and collective which allow the gunner/copilot to operate the helicopter without bending forward or laterally. He may lean back against the seat back and his forearms are well supported on foam pads. The controls are operated by pressure exerted through the hands, wrists, and forearms. Anecdotally, it has been observed that pilots who routinely fly from this position seem to have far fewer back complaints than those pilots who routinely occupy the rear seat which has a standard control arrangement.

Figure 6. Gunner/copilot position in AH-1S Cobra helicopter. Note side-mounted position of cyclic (right) and collective (left) controls.

It is certain that an ergonomically designed cockpit as described above will dramatically reduce the incidence of helicopter pilot back pain. However, it remains uncertain whether additional consideration will have to be given to control of vibration levels as well. It is the author's opinion that an ergonomically designed cockpit in itself will resolve the acute pain problem in helicopter crewmembers. Whether chronic intermittent exposure to low-level vibration causes an increased incidence of degenerative spinal conditions is a separate issue that will require further laboratory and epidemiological study.

Given the current design of most helicopter cockpits, what can be done to prevent back pain in helicopter aircrews? Delahaye et al. have stressed the importance of maintaining good physical condition and routinely engaging in spinal strengthening exercises.[4] They have also suggested radiographic preselection criteria for aviation training to preclude entry of individuals with spinal anomalies who, they feel are at a greater risk for developing problems when exposed to helicopter flight. These measures may have some small impact on reducing the incidence or severity of aviator complaints, but, in general, the author believes that back pain in helicopter crewmembers is simply a normal physiologic response to an injurious stimulus. Therefore, any measures taken short of redesigning crew stations will only be palliative and not curative.

Figure 7a. Pilot in gunner/copilot position of AH-1S Cobra. Arms are supported by rests and back is supported by seat back.

Figure 7b. Pilot in cockpit of UH-1H helicopter. Note increased flexion of lumbar and thoracic spine as compared to same pilot seated in AH-1S.

There are certain measures that crewmembers may take to delay the onset of symptoms or to lessen their severity. As mentioned, many pilots have reported increased comfort when they place a soft cushion in their lumbar region while flying. It may also be helpful to limit the duration of flights as much as possible, and during short breaks between flights it is recommended that crewmembers be encouraged to walk for short distances or perform simple flexion and extension exercises before returning to the helicopter. Waiting in the aircraft or sitting during short stops should be discouraged. The objective is to have crewmembers take advantage of nonflying periods by changing posture and stretching muscle groups that may be prone to spasm. There may also be some advantage to limiting time actually on the controls to 15- to 30-minute intervals by alternating with a copilot rather than the usual practice of alternating piloting duties by flight leg.

In general, crewmembers with transient symptoms do not require any workup when reporting to a flight surgeon. These patients should be instructed on the palliative measures mentioned and returned to flight duty when asymptomatic. On the other hand, crewmembers reporting more persistent symptoms or symptoms suggestive of nerve root involvement probably deserve a workup for herniated nucleus pulposus or other degenerative processes and consideration for temporary or indefinite suspension from flying duties. These patients need to be handled on a case-by-case basis and treatment individualized with the objective of returning them to full flight duties.

Most clinicians agree that the most effective mode of therapy for low back pain is to remove the patient from known provoking stimuli. In the case of helicopter aircrews, this entails a period of grounding, and in severely afflicted individuals, a period of strict bed rest. All should be placed on a program of physical therapy designed to strengthen the spinal and abdominal musculature.

Dealing with the issue of grounding is very difficult for aircrewmembers, their commanders, and flight surgeons. Aircrewmembers are concerned about the likelihood of losing their means of livelihood or having medical problems influence their performance evaluations; commanders are concerned about the availability of manpower; and flight surgeons are usually caught in between. For these reasons, flight surgeons generally only see the severely afflicted aviators in their clinics. Nevertheless, these aircrewmembers should be removed from flight duties as long as they remain symptomatic, and flight surgeons need to insure that they are not placed at desk jobs during their recovery. In most cases, this will require hospitalization or suspension from all duties. When asymptomatic, the patient should be returned to nonflying duties for a period while he maintains a program of physical therapy. If he remains asymptomatic, he may then be returned to flying duties following the recommendations for prevention of back pain discussed above. Permanent suspension from flying duties should be considered if he subsequently experiences a severe and persistent relapse of symptoms.

CONCLUSIONS

1. There is an extremely high prevalence of back pain reported by helicopter flightcrews.

2. For most crewmembers, the pain is transient, precipitated by helicopter flight, and relieved by a variable period of abstinence from flight duties. Nevertheless, for some afflicted individuals, the pain appears to become fixed and may be related to permanent pathological changes in the spine.

3. The most probable etiological factor is poor posture related to inappropriate ergonomical design of the seats and controls in most operational helicopters. Chronic, intermittent vibration exposure in the range of the resonant frequency of the spinous system may aggravate this condition.

4. Prevention of this malady will require redesign of helicopter cockpits according to well-known ergonomic principles. Pending such changes, programs of physical conditioning and, perhaps, stricter aircrew selection criteria are recommended.

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AEROMEDICAL SUPPORT OF HELICOPTER MEDICAL EVACUATION AND RESCUE OPERATIONS

by

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Any helicopter rescue or evacuation mission would seldom be required unless some extraordinary conditions prevailed such as high sea and winds, low clouds, snow, turbulence, cliffs and mountains. This means that aeromedical support to these missions in the planning must have taken into account the type of event possible, the type of aircraft available - and the type of task for the aeromedical crew to be expected. These factors will be of influence for the educational and training programs, for the choice of medical equipment and drugs, etc. Due to the extraordinary conditions it is of vital significance that all parts of the aeromedical support system are kept as simple and consequently as efficient as possible.
Whatever the mission is under war- or peacetime conditions, of short or long duration, and of urban, mountain, or ocean rescue nature, the task will always be the same: human life support. Consequently aeromedical crew must consist of physicians and/or paramedics carefully and specifically trained for this ambitious job. Everyone must be familiar with the particular environment and skilled in emergency medical procedures - and the planning must select proper medical equipment for the properly designed vehicles and the necessary support from suitable hospitals in the health care areas.

INTRODUCTION

The pandemic of sudden illness and injury is apparent in all countries during peacetime and wartime conditions. It is known that organized immediate medical care on the site of an accident and in transit to hospital can save a high proportion of the lives involved. It is also known that time is a potent factor in all medical emergencies where hours and even minutes can spell the difference between life and death.

This is why the advanced and complex sciences and technologies of medicine and flying are drawn together in the field of helicopter medical evacuation and rescue operations. The challenges means that aviation specialists must be constantly aware that medicine has precise requirements for the safe transport of patients in critical conditions, and medical experts must realize that requirements of helicopter flying impose certain limits and constraints on the design of the aircraft and on the mission profiles available. Another field to consider are the differences between the nature of the missions - and the areas where they have to be carried out. Any helicopter rescue or evacuation mission would seldom be required unless some extraordinary conditions prevailed such as warfare - or high sea and winds, low clouds, snow, turbulence, cliffs and mountains, etc. during peacetime.

Further some national differences have to be taken into account. Some nations have relatively compact landmass, and others are surrounded by open water; some nations have a high state of art and level of technology with a good ability to finance aeromedical services; others not. No two nations can ever be exactly alike in these respects mentioned and it would be wise to keep these differences in mind when the principles for aeromedical evacuations and rescue are elucidated.

PRINCIPLES FOR AEROMEDICAL EVACUATION

The first airborne patient evacuation in the world took place during the French-German war 1870-71 at the siege of Paris when 164 patients were rescued by hot air balloons. Other lessons learned from armed conflicts including the use of fixed wing aircraft evacuations from Africa to France in the beginning of this century and the more and more sophisticated air evacuations from the Far East to the United States could first at a rather late stage be defined as aeromedical supported evacuations. But the comparison of death rates in the different armed conflicts during this century indicates that the aircraft - and in particular the helicopter - has been an outstanding vehicle for the greatest variety of life-saving missions. This fact together with many other factors, including improved trauma surgery and equipment, has lead to the demand of getting appropriate life-support to the patients on the site of accident and to maintain the observation and treatment during the transportation - either from the site of accident to the first hospital (primary transport) or from a smaller to a bigger and better equipped hospital (secondary transport).

This development has established some principles and rules for air-evacuation which must be taken into account with the necessary modifications due to the wide variery of conditions where helicopters are used in aeromedical evacuation and rescue. One very important factor is, that the transportation of any patient must be considered an additional trauma by itself. Consequently, it is of significance that the condition of the patients always is related to the type of transportation. It can, however, also be stated that any patient may be carried by air. The journey will often be more comfortable that in a ground ambulance and the reduced time spent in reaching help may be life-saving as mentioned.

There are, however, several special problems attributed to air transport, which vary with the type of aircraft and mission profile used, the length in time of the flight, the patients age, diagnosis, and clinical condition, etc. These problems should always be considered before an aeromedical evacuation is authorized and startet.

EFFECTS OF FLYING

Hypoxia:

As helicopters normally not are equipped with a pressurized cabin the partial pressure of oxygen will fall as a direct consequence of the increase in actual aircraft altitude. Ambient pressure at 8000 feet (2438 m) - which is about the maximum cabin altitude to which a healthy individual should be exposed for a longer period of time - is 74.7 kPa (560 mmHg), which gives an inspired oxygen tension of 15.3 kPa (115 mmHg) and an alveolar tension of 8.7 kPa (65 mmHg). Thus, any patient with impaired lung or cardiovascular performance, though able to cope adequately on the ground, may be severely effected of these levels.

If the arterial oxygen tension in patients at risk is known, the need for added oxygen must be assessed in due time, or the mission profile kept at a flying level which copes with the condition of the patient.

Dysbarism:

Gasses expand with falling ambient pressure in accordance with Boyle's law. At 10.000 feet there will be an expansion of gas with a factor of about 1.5 and a similar contraction during descent. Even flying with helicopters at a relatively low altitude can lead to expansion of gas above the surface of fluid in a rigid intravenous infusion container. This will speed up the drip flow during climb and slow it down during aircraft descent unless the air is vented by a tube to cabin atmosphere. Similarly, air in the cuff of an endotracheal tube or tracheostomy tube will expand, causing increased pressure on the tracheal wall. During descent the contraction may cause a leak past the deflating cuff, which is of particular interest since this not necessarily will be noticed because of the high background noise.

Conditions such as pneumothorax, trapped air in the abdominal cavity, eye, or brain should be sufficiently drained before transportation. A special attention should be paid to air splints which may become tense enough to obstruct the circulation to the limb even at altitudes of 1500-2000 feet unless excess pressure is relieved.

Transportation of patients with decompression sickness may be carried out either by use of a transportation hyperbaric chamber or by use of a mission profile with the helicopter almost flying at sea level altitude.

Acceleration:

The accelerative forces of significance during patient evacuation are the Gz-accelerations which act in the longitudinal axis of the body. The Gz-acceleration tends to move the blood mass from the head to the feet (positive Gz) or vice versa (negative Gz). This effect may be very detrimental to patients in shock or to patients with extended burns, if the transport is carried out by for instance a jet aircraft. The use of helicopters, in contrary, is in particular beneficial to patients with these diseases, since the mission profile is almost free of Gz-effect to the patient.

Vibrations:

The effect of vibrations on any organism depends on the intensity and frequency of the vibrations, and on the duration of exposure. It is in particular the frequency between 0 and 150 Hz which may have a deleterious effect on a patient during transport.

Investigations on the significance of vibrations are still rather few in the area of air-evacuation. But it has been reported that low frequency vibrations immediately increase the total metabolic rate and consequently the oxygen consumption with up to 40% of basic rate. This is probably due both to an increased tonus of the muscles as a direct answer to the vibrations and a sort of a stress induced energy increase caused by an increased catecholamine secretion to the plasma. The type of respiration at this vibration-induced elevated oxygen uptake is often a hyperventilation with decrease of the CO_2-tension in the arterial blood as a consequence.

Investigations on the circulation indicate that short-lasting exposures to a frequency of 4-11 Hz will be followed by an increase in heart rate with 50-60% of the basic values, accompanied by a peripheral vasoconstriction and from time to time by multifocal extrasystoles. The minute-volumen of the heart is increased but this is mainly due to the increase in heart rate since the stroke volume remains unchanged.

Although only case-reports describe the deleterious effects of low frequency vibration to patients it is, however, the general opinion that in particular helicopters may

have a disstressing influence on patients with an insulted cardiac function or vascular system. It is therefore of utmost importance that such patients are evaluated in relation to the effect of helicopter-flying and observed closely during the transport as some types of helicopters present especially these low frequency vibrations during flight.

Noise:

Noise levels in modern helicopters have been reduced, but they are still high enough to make for instance the use of a normal, not amplified stetoscope of little value. This means that normal diagnostic tools and signs as auscultation, air leaks around a tracheostomy tube or the sounds of a ventilator not are available. Repeated observations and measurement of other parametres are therefore mandatory, and the use of an ECG-monitoring throughout the flight is of great value.

It should be remembered that ear defenders are necessary - even when the patient is unconscious!

Turbulence:

Turbulence and vibration may together increase the incidence of motion sickness which in particular for patients with fixated jaws may be dangerous.

As for crewmembers and other passengers a means of restraint system for the patient and the litter is essential.

HELICOPTERS AS MOBILE INTENSIVE CARE UNITS

Recognizing the importance of the effect of one or more of the transport-traumas mentioned, another important factor for consideration is the demand to the vehicle as such. If it is estimated that the patient can be transported without special observation or treatment the air evacuation can naturally be carried out with a smaller helicopter without medical care or equipment. But if the condition of the patient indicates the needs for special observation and treatment during the transport a sort of a mobile intensive care unit should be demanded so that the patient to the widest extent possible can benefit from the lessons learned during the last years in the intensive care units of the hospitals.

The demands to a mobile intensive care unit can be listed in this way:

1) The cabin must be big enough to permit possibilities for observation and treatment of the patient during the transport.

2) The cabin must be designed and equipped so that intensive observation and treatment of vital organ-functions can be carried out during the transport.

3) The crew - which should include a physician - must be familiar with the special environment of the vehicle. This demands a special education and continuous training.

4) The mobile intensive care unit should be on stand-by 24 hours a day, 52 weeks a year with the shortest possible alert-time.

5) The influence of the transport should be as gentle as possible as any transport is considered o be a trauma by itself.

6) The transport time should be as short as possible.

The extensive use of helicopters mainly during peace-time the last 10-15 years has proven to be valuable in pre-hospital emergency care in a wide variety of emergency situations, including water rescue, mountain rescue, high-rise building fires, and highway accident transportation.

There should, however, be a warning regarding their misuse, especially in the areas of costs, of safety, and of substandard on board medical care.

COSTS

Figures from various institutions show that, where a rescue helicopter is used frequently by other services such as military, police, or traffic control, then the cost per patient may be as low a US$ 100 per admission. However, in the majority of cases where there is little demand for helicopter use other than for medical transportation, the costs lies between US$ 400 and 1000 per patient.

These figures suggest that communities and nations in their disaster medical readiness planning to the widest extent try to establish a narrow collaboration between civilian and military authorities.

SAFETY

There is no question that worldwide figures for helicopter accidents are high, especially in abnormal weather and difficult outback areas. The misuse of helicopters for inappropriate patient transportation is also of concern, particularly when evacuation of patients with minor injuries has been accomplished with risk, when other means of transportation could have been used if there had been better initial communication.

It has been stressed for many years in emergency care that the use of a helicopter to transport the injured or sick should be a decision based on an awareness of risk and a knowledge of the hazards, both physiological and practical. The decision to use a rescue helicopter in any particular case should be made by a senior officer with a rescue expe-

rience that includes emergency medical care and flying safety.

ON BOARD MEDICAL CARE

Education:

If the helicopter is to be used as an air ambulance or even mobile intensive care unit it is of greater importance that the experience of the crew members is high enough to cope with the insulted patients during often difficult rescue missions. Specialists from many countries insist that any rescue and air evacuation service crew includes a doctor and/or paramedic. Physicians allocated this duty will have to perform one of the most difficult and demanding disciplines, emergency medicine. Consequently, they should all have an appropriate clinical experience after medical licence and in addition a post-graduate educational program not only in aviation medicine but in particular with emphasis on acute or disaster medicine. Supervised practice should involve at least anasthesiology, chest and abdominal traumatology, acute extremity surgery, treatment of cardial disorders and acute central nervous system injury, and acute psychiatry. Furthermore, the pathophysiology and management of drowning and accidental hypothermia should be intensively rewieved in areas with cold water and possibility of exposure to cold as for instance in the mountains.

The educational program should further include training in basic aviation so that the physician is a part of the crew during the missions. The training might include lectures in basic navigation, radio procedures, air control, meteorology, and the rudiments of flying. In case the actual helicopter type is equipped with a hoist the physicians should practice hoisting procedures under drills from land, sea, and dinghies, so that they can descend onto a ship for an immediate appraisal of the patients conditions and, if necessary, start treatment before evacuation to the helicopter.

This preparation in flying and operational procedures is of tremendous importance, since the physicians only then will be able to participate professionally in the missions performed in an efficient and safe way.

Equipment:

Scarcely any two rescue systems are identical, and scarcely any two rescue or transport operations within the same system will be the same. For this reason the aircraft must carry many different types of equipment as, for instance, a single or double harness for lifting patients especially from the sea. These harnesses are amazingly gentle to even severely injured individuals and often easier and quicker and thereby more safe to use than the baskett or stretcher normally included in a helicopters equipment. Some helicopters can even carry a patient in his own hospital bed, which is a method especially beneficial to burn cases and cases with an injured spinal cord. If the patients are believed to be suffering from highly infectious or contagious diseases the normal equipment should be supplemented by a stretcher transit isolator designed to provide maximum microbiological security to the crew members.

The helicopters should in principle be considered as all-purpose-transportation-units why there should be sufficient equipment on board to cope with all sorts of possible problems during flight. One example from an air evacuation and rescue system is the Search and Rescue Squadron from the Royal Danish Air Force which is the only helicopter unit for this kind of work used in Denmark.

From 1973 to 1982 the squadron accomplished almost 4.000 missions with its Sikorsky S-61 helicopter. More than 95% of the missions were devoted to civilian activities and public health service. The categories of this aeromedical support were:

Trauma	34.8%
Abdominal disease	15.4%
Heart-Lung disease	12.0%
Burns	6.0%
Drowning / accidental hypothermia	5.4%
Disorders of central nervous system	4.2%
Poisoning incl. metabolic disorders	4.1%
Obstetrics	3.5%
Decompression sickness	2.5%
Infectious disease	1.3%
Miscellaneous incl. no injured persons transported	10.8%

This distribution of medical categories indicates a development from just a rescue service into a type of mobile intensive care unit where the helicopter cabin is designed for patient observation and treatment and equipped with apparatus for oxygen, suctions, ECG with defibrillator, 12 volt incubators, and respirators along with a variety of medical gear and drugs. The composition of drugs should, of course, be sufficient for the necessary therapy on board. It is, however, a common experience that all parts of an aeromedical system - including the collection of drugs - should be kept as small and simple as possible for the efficiency.

The on board medical care will under optimal conditions secure that an aeromedical helicopter evacuation and rescue service at any time is qualified to fulfil the doctrine for an emergency medical care system, which involves the following:

1) to insure survival of the most severely injured,
2) to resuscitate and treat on the spot those victims who cannot tolerate transportation to a hospital without this primary treatment, and
3) to rewiev the various categories of injured so that these may be transported in optimal condition to hospitals with amber observation and eventually treatment during the transportation.

HUMAN LIFE SUPPORT

Experience from various systems with aeromedical support in helicopter evacuation or rescue operations during peacetime has shown that there has been no special difficulty in performing these efforts within the aircraft - if the cabin of the vehicle is big enough and equipped to act as a mobile intensive care unit; if the crew is educated in advanced first aid; and if the rescue physician in addition to his education in emergency medicine also is trained as a crew member flying under all conditions.

In most countries centralisation of acute receiving wards with their elaborate medical equipment and highly skilled medical specialist services within the large hospital complexes has already been undertaken, while smaller hospitals are or will be used for less acute service. This evolution means consequently that air-ambulance service has to be refurbished in such a way that all areas in the country can be served rapidly and effectively, and the patients benefit from the experiences achieved in the intensive care units in the hospitals during the transport.

Although there as mentioned are wide variations in the possible tasks from nation to nation and from system to system, peacetime or wartime, urban, mountain, or ocean nature, the endeavour of human life support should always be the common feature.

With this in mind the emergency or disaster medical planning or readiness means that a community or nation is prepared to react promptly in order to save lives and protect property if the community or the nation is hit by a disaster or major emergency at any time - during peace- or wartime. Emergency or disaster readiness requires that planning and preparatory actions including continuous training be taken before there is an emergency or disaster. The medical support authority must in the planning and training be directed against its special environment and obligation - constantly trying to keep the preparation as taskrelated as possible, and the choice of medical equipment and drugs as simple and consequently as efficient as possible.

Air evacuations have their origin during warfare. They are, however, refined during the last years as a consequence of the advantages seen in hospital care and technology and in the construction of modern, appropriate aircraft - in particular helicopters.

The ambitious demands to the different programs developed must continue also during conditions and situations with mass casualties - and also during air evacuation at war. Although war will necessitate many waivers from daily peacetime work the principles elaborated and trained during routine emergency situations should be respected. Different types of helicopters will be used under very different and difficult conditions. The 'peace-time' mobile intensive care unit or aeromedically supported helicopter evacuation service can under warfare only be expected to be used from the main dressing station (second echelon), and evacuation of war-epidemics like soldiers hit by chemical agents can only be expected to be carried by helicopters, if the patients have been intoxicated but not contaminated by a nerve agent.

The civilian and military systems are preparing for a collaboration in war. The extent of cooperation in peacetime disaster situations between civilian services and the military depends on tradition, history, and political systems. The more implemented into the public health services the expensive but normally efficient military apparatus and organization can be, the more skilled, experienced, and professional will the aeromedical support to helicopter medical evacuation and rescue operations be - in peacetime and wartime.

CONCLUSION

Aeromedical support of helicopter medical evacuation and rescue operations is under all circumstances human life support.

Consequently, aeromedical crew must consist of physicians and paramedics carefully and specifically trained for this ambitious job. Everyone must be familiar with the particular environment and skilled in emergency medical procedures for peace- and wartime. The planning must select proper medical equipment for the properly designed vehicles.

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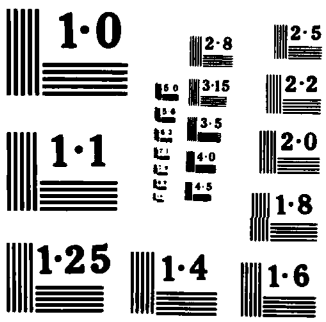
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14. Abstract

This Lecture Series is intended as a comprehensive update for the flight medical officer and other personnel providing aeromedical support for military helicopter operations. Areas that are addressed include:

- stressful missions such as nap-of-the-earth flying, night operations, and operations under other unfavourable circumstances;
- extended operations, aircrew fatigue, and its monitoring and prevention;
- applied visual physiological requirements/standards for helicopter flight;
- visual protection and enhancement;
- perceptual illusions, their generation and disorienting effects in helicopter flight;
- training and adaptation for countering disorientation;
- acoustical hazards, auditory injury, hearing protection, and communications noise reduction; applied countermeasures for environmental extremes and the chemical warfare environment;
- helicopter accident and crash injury analysis, safety and crashworthiness design, and injury prevention;
- epidemiology, etiology, and prevention of back pain in helicopter pilots; and
- helicopter medical evacuation and rescue operations including evacuation of combat casualties.

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